DISSERTATION THIRD:

EXHIBITING A GENERAL VIEW OF THE

Progress of Chemical Philosophy,

FROM THE EARLY AGES TO THE END OF THE EIGHTEENTH CENTURY.

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DISSERTATION THIRD.

SECTION I.

GENERAL VIEW OF THE PROGRESS OF CHEMICAL SCIENCE, FROM THE EARLY AGES TO THE END OF THE SEVENTEENTH CENTURY.

The phenomena of the universe present a series of changes, of which the regularity and harmonious succession excite the surprise of superficial observers, and awaken the admiration and attention of the philosophick mind.

These changes are either accompanied by visible motion susceptible of measurement, and relate to the exterior forms and mechanical characters of bodies, or they depend upon the mutual agencies of the elementary principles of matter, upon its composition, upon its susceptibility of acquiring new properties by entering into new combinations.

The investigation of the former phenomena belongs to the mechanical philosopher; to trace the causes of the latter, and to discover the laws to which they are obedient, is the business of Chemical Science.[1]

[1] *Definitions of Chemistry.*—" La Chymie est un art qui enseigne à separer les differentes substances qui se rencontrent dans un mixte." (L'Emery, *Cours de Chymie.*)

Chemistry, considered as a branch of scientifick inquiry, is not of ancient date.[1] Founded upon principles deduced

[1] "Chemistry is that science which examines the constituent parts of bodies, with reference to their nature, proportions, and method of combination." (Bergman, *Essay on the Usefulness of Chemistry.*)

"Chemistry is the study of the effects of heat and mixture, with a view of discovering their general and subordinate laws, and of improving the useful arts." (Black, *Lectures.*)

"La Chimie est une science qui apprend à connaitre l'action intime et réciproque de tous les corps de la nature, les uns sur les autres. Par les mots *action intime*, et *reciproque*, cette science est distinguée de la physique experimentale, qui ne considère que les propriétés extérieures des corps doués d'un volume, et d'une masse quon peut mesurer, tandis que la Chimie ne s'attache qu'aux propriétés intérieures, et n'agit que sur des molécules, dont le volume et la masse neu peuvent pas être soumis aux mesures et aux calculs." (Fourcroy, *Systême des Connoissance Chimiques*, Vol. I. p. 4.)

"Die Chemie ist eine Wissenschaft die uns die wechselseitige wirkungen der einfachern Stoffe in der Natur, die zusammensetzung der körper aus ihren und nach ihrdn verschiedenen verhältnissen, und die Art und Weise kennen lehrt, sie zu trennen, oder sie wieder zu neuen Körperarten zu verbinden." (Gren. *Systematisches handbuch der Chemie*, p. 1. Halle, 1794.)

"Chemistry is that science which treats of those events or changes in natural bodies, which are not accompanied by sensible motions." Thomson, *System of Chemistry*, fifth edition, p. 2.)

Most of the substances belonging to our globe are constantly undergoing alterations in sensible qualities, and one variety of matter becomes, as it were, transmuted into another. Such changes, whether natural or artificial, whether slowly or rapidly performed, are called chemical;—thus the gradual and almost imperceptible decay of the leaves and branches of a fallen tree exposed to the atmosphere, and the rapid combustion of wood in our fires, are both chemical operations.

"The object of chemical philosophy is to ascertain the causes of all phenomena of this kind, and to discover the laws by which they are governed." (Davy, *Elements of Chemical Philosophy*, p. 1.)

In the edition of Johnson's *Dictionary*, now publishing by the Rev. H. J. Todd, the erroneous and antiquated definition of Boerhaave is very improperly retained. "An art whereby

from experiment and observation, centuries were consumed in their accumulation and systematic arrangement; but, as

sensible bodies contained in vessels, or capable of being contained therein, are so changed by means of certain instruments, and principally fire, that their several powers and virtues are thereby discovered, with a view to philosophy or medicine."

The derivation of the word Chemistry can scarcely be said to have been ascertained. The most plausible guesses are the following: from χυω to melt, or χυμος juice; from *kema*, an oriental word signifying *black;* from χιμης, the name of a person eminently skilled in the sciences; from *Chêmi*, the Coptick name of Egypt, where the art is supposed to have had its rise.

According to Bryant (*Ancient Mythol.*), it is derived from *chemia*, and that word from *Cham.*

The Rev. Mr. Palmer, Professor of Arabick at Cambridge, has given the following etymology: "Al-chemy, or more properly Al-kemy, the knowledge of the substance or composition of bodies, so named from the substantive (Kyamon,) that is, the substance or constitution of any thing; from the root (Kama.) Golius. *Lexicon.*" (Thomson's *Chemistry*, 5th edit. p. 4. Note.)

Conversing upon this subject with Dr. Thomas Young, he remarked, that the Egytians probably neither knew nor cared much about the *composition* of bodies; and the term of Chemistry, as referring to the secret art of transmutation, was probably derived from the Coptick root *hhems* or *chems*, signifying *obscure, dark.* The German word *geheim*, *secret*, he said, was perhaps of the same root.

"Haec ars varia accepit nomina, nam omnium primò dicta fuit τεχνη ποιητικη, et antiquis illis temporibus per hanc significabant artem vilia metella in aurum convertendi, et ejus artifices ποιηται vocari Zozimus dicit. Veteres Aegyptios hanc artem *Chamoet* vocasse Josephus Scaliger ibi ostendit, sed postea Graeci hanc artem χρυσοποιησιν dixerunt, Arabibus vero, *Alchemia.*" (Boerhaave, (*Institutiones Chemiae.*)

[1] "Tout ce qu'on a dit de l'antique origine de la Chimie, sur les premiers hommes qui ont travaillé les metaux, taillé et poli les pierres dures, fondu les sables, dissous et crystallisé les sels, ne montre à un esprit exact et sévère qu'une vaine et ridicule pretension, semblable à cette par laquelle on voudrait reconnoître les élémens de la géométrie dans l'ouvrage grossier du sauvage qui use les fragmens du rocher, qui leur donne des formes à peu près régulières pour les rendre utiles à ses premiers besoins." (Fourcroy, *Discours Préliminaire.*)

an art, chemistry is readily traced to periods of remote antiquity; for it is obvious that the chemical changes of matter must have been rendered subservient to the wants of mankind in the earliest ages of the world.

Metallurgy is among the most ancient of the arts, and Tubal Cain, the instructor of workers in iron and brass, has thence been called the inventor of chemistry. Others have preferred the claims of Noah, to whom the invention of wine has been attributed; but these, and other arts alluded to in Sacred Writ, such as dyeing, gilding, and embalming, which have been adduced as instances of chemical knowledge in the time of Moses, prove nothing more than that such processes were practised at that period, independent of each other, and quite unconnected by the slightest reference to general principles.[1]

It is probable that the early mythological systems of the Egyptians contained some allusions to the chemical changes of matter, and to them the first speculations on the art of transmutation have been attributed. Hermes, or Mercurius Trismegistus, the favourite minister of the Egyptian king Osiris, has been celebrated as the inventor of this art, and the first treatise upon it has been attributed to Zosymus, of Chemnis or Panopolis in Egypt. The inhabitants of Sidon and Tyre, those renowned seats of the commerce of the ancient world, seem to have been skilled in some

[1] "Si l'on examine cependant avec courage et sans préjugé toutes les preuves qu'on a réunies pour etablir l'existence de la Chimie chez les Egyptiens, après avoir reporté son origine aux premiers âges du monde, et aux prémiers travaux ou les hommes ont employé le feu comme agent, on reconnaît bientôt que tirées uniquement des products employés dans leurs constructions diverses, elles peuvent toutes annoncer des arts ou des procédés de fabrique plus on moins avancés mais rien qui tienne à des notions générales tirées de ces arts comparés, rien qui depende d'une doctrine suivie, rien enfin qui puisse donner une idée d'une veritable science." (Fourcroy, *Disc. Prél.*)

chemical manufactures ; they made glass and artificial gems, and excelled in dyeing purple.

Egypt maintained its superiority in arts until the invasion of Alexandria by the Saracens, when the celebrated library collected by the Ptolemies, with great diligence and at enormous expense, was burned by the orders of the Caliph Omar.[1] The alchemical works had been previously destroyed by Diocletian in the fourth century, lest the Egyptians should acquire by such means sufficient wealth to withstand the Roman power. On the present occasion, about seven hundred thousand volumes were seized, which we are told supplied six months fuel for forty thousand baths, that contributed to the health and convenience of the populous capital of Egypt.

When philosophy declined in Egypt and in the East, Greece became the principal seat of learning and of the arts ; but the system of their early philosophers, of Thales[2] the founder of the Ionick sect, of Anaximander, and Anaximenes, breathe the sentiments of the Egyptian schools. By Thales, water was considered as the source of all things, as the universal element. The opinions of Anaximander, in themselves unintelligibly obscure, received some elucidation from his successor Anaximenes ; they regarded air and fire as the first rudiments of matter.

The result of the Macedonian war introduced Grecian philosophy into Italy, and the doctrines of Plato,[3] and Aristotle, and Theophrastus, prevailed in the school of Rome.

Among the early Roman philosophers, Lucretius[4] stands preeminent ; but his opinions had been formed at Athens,

[1] "Qui his scriptis parcendum esse negabat, quippe quae inutilia essent, si eorum dogmata Alcorano congruerent, noxia vero, si ab illo dissentirent." (Bergman, *De primordiis Chemiae.*)

[2] 500 years B. C. [3] 340 years B. C. [4] 50 years B. C.

in the Stoick school of Zeno, and he early imbibed the doctrines of Empedocles and Epicurus, which are expounded with superiour genius and admirable ingenuity in his masterly poem on the *Nature of Things*.

The celebrated Natural History of the elder Pliny, written in the first century of the Christian era, contains an account of the rise and progress of the arts and sciences previous to that period, which, though not always accurate, often obscure, and sometimes unintelligible, abounds in instructive documents and interesting remarks. It is written, not in the elevated, refined, and elegant style of the Augustan age, but in the language of the laborious and liberal historian, frequently led by the extent of his inquiries to subjects which he is incompetent to manage, and upon which his opinions are incorrect, his conjectures vague, his assertions ill founded.

The origin of many of the follies and mysteries of Alchemy may perhaps be referred with most propriety to the *New Platonists*, whose rise marked the declining age of learning towards the end of the third century of the Christian era. These philosophists, celebrated for their metaphysical disputes and superstitious notions, credited the existence of demons and spirits, with whom they claimed familiar intercourse. Neglecting useful knowledge, they exhausted their strength in verbal disputes, and in attempts to discover the secrets of the invisible world; thus gradually converting the study of philosophy into that of demonology and magick. "Several of these masters," says Gibbon, "Ammonius, Plotinus, Amelius, and Porphyry, were men of profound thought and intense application: but, by mistaking the true object of philosophy, their labours contributed much less to improve than to corrupt the human understanding."

Porphyry died about the time of Diocletian's abdication. The life of his master, Plotinus, which he composed, gives a complete idea of the genius of the sect, and the manners of the Professors. This curious piece is inserted in Fabricius. (*Bibliotheca Graeca*, Tom. IV.) When the cultivated part of Europe was overwhelmed by the barbarous nations, all records of arts and sciences possessed by the Greeks, and by their Roman successors, were swept away in the general destruction, and now the Arabians became the protectors of philosophy, and the promoters of its pursuits. To them, Chemistry, regarded as a distinct branch of experimental philosophy, owes its origin, and several circumstances co-operated to render its progress rapid, which are important in their relation to the subsequent advances of the science. Among these the mysteries of Alchemy, so well adapted to the genius of that age and people, are the most remarkable. Of this occult art, the two leading objects were the *transmutation* of common metals into gold and silver, aud the discovery of the *universal medicine*, which, by the removal and prevention of disease, should confer immortality upon the possessors of the secret.

The origin of these chimerical notions has been variously accounted for. The idea of transmutation may plausibly be referred to the various processes to which natural bodies were submitted by the astrological experimentalists of the seventh and eighth centuries. Observing the change of properties in metalick ores by exposure to heat, and the production of malleable and useful metals from their brittle and useless compounds, it is not surprising that superficial observation and incorrect reasoning should lead to a belief in their production and transmutation; and such speculations, not without apparent foundation, holding out attraction to the ambitious, and hope to the needy, would soon excite

notice, and command followers. That this was the case, the records of those times amply testify.

The pursuit of the other object may be referred to the success attending the medical employment of many of the chemical preparations. Pharmacy was becoming enriched by the introduction of chemical compounds ; and remedies for diseases, before deemed incurable, were occasionally discovered among the products of the furnace. Hence, perhaps, the possibility of the existence of an universal remedy might occur to those under the infatuations of the black art.

The earliest of the true Alchemists, whose name has reached posterity, is Geber,[1] supposed to have been an Arabian prince of the seventh century. The works attributed to Geber, several of which have been published in Latin translations by Golius, and others in English by Russell, are numerous and curious. They abound in the cant and jargon of the hidden art. Some have asserted his pretensions to the possession of the universal medicine, for he speaks of curing disease. But this seems a mere metaphorical expression, relating to transmutation. "Bring me," says he "the six lepers, that I may cleanse them;" by which he doubtless would imply the conversion of silver, mercury, copper, iron, tin, and lead, into gold,—there be-

[1] "Primus omnium Arabum post Graecos est *Geber,* cui dant titulum Arabis. Alii dicunt eum fuisse regem, unde *rex Geber Arabs*, dici solet; sed *Leo Africanus*, qui Graecus fuit et multa descripsit ex antiquis Arabibus, dicit, Gebrum illum natione Graecus fuisse, sed derogasse suam religionem, et se dedisse Mahomedae religioni Arabum, et vixisse septimo seculo." (Boerhaave.)

Geber was also a physician and astronomer. The following are the principal works on Chemistry, which have been attributed to him: *De Alchemia,—De summâ perfectione Metallorum,—De Lapide Philosophico,—De inveniendi arte Auri et Argenti.* These, and some other works bearing his name, whether genuine or not, furnish good specimens of the early alchemical writings.

ing only these seven metals known at that period. Dr. Johnson supposes that the word *Gibberish*, anciently written *Geberish*, was originally applied to the language of Geber and his tribe.

The elder Mesue and Avicenna,[1] physicians of the ninth and tenth centuries, have given some account of the Chemistry of their age, but their works relate chiefly to medicine. Indeed, it is probable, that the writings now extant in the name of the former are spurious.

The twelfth, thirteenth, and fourteenth centuries, abound in writers on the secrets of Alchemy ; and the happy few to whom fate and metaphysical aid had granted the discovery of the great secret, assumed the title of *adepts*, a character which required to be sustained by superiour feats of deception and duplicity.

About this period, several circumstances happily concurred, favourable to the diffusion of learning and the arts, which began again to dawn in Europe with promising splendour.

The extravagant expeditions of the Crusaders tended, in these respects, to the most extensive, beneficial, and permanent consequences. In their progress to Palestine, these ardent followers of the Cross traversed countries which, compared with their own, were cultivated, civilized, and refined. Their minds and manners were thus enlarged and improved, and new customs and institutions attracted their notice.

In Constantinople, then the largest and most magnificent of European cities, some traces of ancient elegance and refinement were still to be found, and many of the natural

[1] Avicenna introduced several important drugs into the *Materia Medica ;* and the art of making sugar has been enumerated among his discoveries, although, doubtless of earlier date.

products and of the manufactures of the East were offered to their notice.[1]

We accordingly discover in these superstitious and enthusiastick expeditions the source of many improvements, which afterwards raised Europe to the highest rank among nations; which tended to dispel barbarism, to mitigate the fury of war, and to extend commerce; and which ultimately led to the cultivation of the useful and fine arts, and to the diffusion and exaltation of science.

Another event occurred about this period, which miraculously facilitated the acquisition and propagation of learning, namely, the invention of printing, which, as it were by superhuman mediation, advanced so rapidly to perfection, that the finest specimens of typography are to be found among the early efforts of the art. It was introduced into England by the Earl of Rivers, in the reign of Edward IV.[2]

Of the earlier writers on Chemistry, no one is more deserving notice than the celebrated Roger Bacon, a native of Somersetshire, who flourished in the thirteenth century. His writings, though troubled and polluted by the reigning absurdities of Alchemy, contain many curious facts and judicious observations. To him the discovery of gun-

[1] "The first and most obvious progress was in trade and manufactures,—in the arts, which are strongly prompted by the thirst of wealth, the calls of necessity, and the gratification of the senses or vanity. Among the crowd of unthinking fanaticks, a captive or a pilgrim might sometimes observe the superiour refinement of Cairo and Constantinople. The first importer of windmills was the benefactor of nations; and if such blessings are enjoyed without any grateful remembrance, history has condescended to notice the more apparent luxuries of silk and sugar, which were transported into Italy from Greece and Egypt." (Gibbon, *General consequences of the Crusades*, Vol. XI. p. 289. Edit. 1813.)

[2] Hume. Edward V.

powder has, with all appearance of justice, been attributed.[1] "From saltpetre and other ingredients," he says, "we are able to form a fire which will burn to any distance." And again, alluding to its effects, "a small portion of matter, about the size of the thumb, *properly disposed*, will make a tremendous sound and coruscation, by which cities and armies might be destroyed." And again, in the same work, is a passage which, though somewhat enigmatical, is supposed to divulge the secret of this preparation. "Sed tamen salis petrae, *luru mone cap urbre*, et sulphuris, et sic facies tonitrum si scias artificium." The anagram is convertible into *carbonum pulvere*. Such are the claims of Roger Bacon to a discovery which soon changed the whole art of war.

The works of Bacon most deserving perusal are the *Opus Majus*, edited by Dr. Jebb in 1733; and his *Epistola de secretis Operibus Artis et Naturae, et de nullitate Magiae*. Paris, 1532. The former, addressed to Pope Clement IV., breathes sentiments which would do honour to the most refined periods of science, and in which many of the advantages likely to be derived from that mode of investigation insisted upon by his great successor Chancellor Bacon, are anticipated.

Raymond Lully, Arnold of Villanova,[2] John de Rupescissa, and Isaac and John of Holland,[3] were Alchemists

[1] Watson's *Chemical Essays*, Vol. I.

It has been by some imagined, that Roger Bacon invented the air-pump; but the idea rests upon very doubtful expressions. (Boerhaave, *Instit. Protegom.*)

[2] Raymond Lully was born in Majorca in 1236, and Villanova in Provence 1235. Their writings are as obscure as they are voluminous.

[3] "Sequuntur nunc Johannes et Isaacus Hollandus, pater et filius, qui diffusissimo sermone et magna eloquentiâ scripserunt, et si unum vel alterum arcanum exceperis, pulcherrima experi-

of the thirteenth, fourteenth, and early part of the fifteenth century. Their writings are extremely numerous; and they each treat of the philosopher's stone, and other secrets of the occult science.

Basil Valentine of Erfurt, who wrote towards the end of the fifteenth century, is deserving of more attention, and ranks among the first who introduced metallick preparations into medicine. In his *Currus Triumphalis Antimonii*,[1] after setting forth the chemical preparations of that metal, he enumerates their medicinal effects. According to the notions of the age, he boasts of supernatural assistance; and his work furnishes a good specimen of the controversial disputes between the chemical physicians and those of the school of Galen,---the former being attached to active remedies, the latter to more simple and inert medicines. The *Chariot of Antimony* opens with the most pious exhortations to prayer and contemplation, to charity and benevolence. But the author, soon forgetting himself, breaks out in the following strain of virulent invective. "Ye wretched and pitiful medicasters, who, full of deceit, breathe out I know not what Thrasonick brags;---infamous men, more mad than Bacchanalian fools! who will neither learn, nor dirty your hands with coals! you titular doctors,

menta fecerunt de sanguine et urinâ humanâ, quae Helmontius postea et Boylaeus pro recentioribus inventis habuerunt." (Boerhaave.)

[1] It is probable that the word Antimony was first used by Basil Valentine. Tradition relates, that having thrown some of it to the hogs, after it had purged them heartily, they immediately fattened; and, therefore, he imagined, that his fellow monks would be the better for a like dose, they having become lean by fasting and mortification. The experiment, however, failed, and they died; whence the medicine was called *Antimoine*.

He published several other works besides the *Currus Triumphalis Antimonii*. See Chalmer's *Biograph. Dict.*

who write long scrolls of receipts; you apothecaries, who with your decoctions fill pots no less than those in princes' courts, in which meat is boiled for the sustenance of some hundreds of men; you, I say, who have hitherto been blind, suffer a collyrium to be poured into your eyes, and permit me to anoint them with balsam, that this ignorance may fall from your sight, and that you may behold truth as in a clear glass. But," says Basil Valentine, after a long exhortation in this strain, "I will put an end to my discourse, lest my tears, which I can scarcely prevent continually falling from my eyes, should blot my writing, and, whilst I deplore the blindness of the world, blemish the lamentation which I would publish to all men."

Such is the trash in which these authors abound, and in which curious facts and ingenious speculations are often enveloped.

Basil Valentine was succeeded by the more celebrated Paracelsus, a native of a village near Zurich in Switzerland.[1] In this remarkable person, all the follies and extravagance of the Alchemists were united;---he pretended to the discovery of the grand secret of the universal remedy; and his writings, which are very numerous, overflow with the whims and oddities of the sect; his zeal was more directed to the acquisition of popularity than to the advancement of science; his enthusiasm was ever misemployed; and he sought the elevation of his own character

[1] He assumed the formidable title of Philippus Aureolus Theophrastus Bombastus Paracelsus ab Hohenheim.

"Hunc virum," says Boerhaave, "alii coluerunt pro Deo, imo locutus sum cum hominibus qui credunt eum non esse mortuum, sed vivum sedere in sepulchro pertaesum peccatorum et malorum hominum." The following is an illustrative anecdote of his impudence: "Cum adscenderet Cathedram physico-medicam, sumsit vas aeneum cum igne, immisit sulphur et nitrum, et simul Galenum, Avicennam, et Arabes conjecit in ignem, dicens, sic vos ardebitis in gehennâ."

in the abuse and depreciation of his predecessors and contemporaries. He terminated a life, stained with every vice, and deficient in every virtue, in the year 1541, at an obscure inn at Saltzbourg, in Bavaria.

In the history of medicine, Paracelsus deserves more honourable mention; for he enriched the *Materia Medica* with many powerful remedies, derived from the mineral world, among which several preparations of mercury deserve especial notice; nor was he unacquainted with the virtues of opium, and other powerful drugs of vegetable origin. These he administered with a daring but often successful hand, and gained such celebrity, that, in 1527, he was promoted by the magistracy of Basle to the office of Professor of Physick. In this he expounded his own doctrines, asserting that that which was denied him from above had been granted by the infernal deities; and that to them he was indebted for those great secrets of physick and philosophy which he should divulge for the advantage and salvation of his hearers. Paracelsus, however, soon became weary of his situation, and terminated his professorial career, which was ill suited to his genius and inclinations, in the year 1528; he left Basle, and his subsequent life was one disgusting scene of dissolute irregularity.

The last person whose name deserves to remain upon the chemical records of the sixteenth century is Van Helmont of Brussels, born in 1577,[1] who, at an early age, made considerable progress in philosophical studies. As a physician, he adopted the doctrines of the chemical school, and rejected those of Aristotle and Galen; he effected cures so numerous and surprising, that he was accused by

[1] The year 1558, given in Moreri, *Dictionnaire Hist.* is obviously incorrect, "Anno 1594, qui erat mihi decimus septimus," &c. (Van Helmont, *opera omnia*, 1707. *Studia Authoris.*)

the inquisition of employing supernatural means, which induced him to retire into Holland. The writings of Van Helmont are chiefly upon medical subjects; those connected with chemistry contain some curious speculations respecting aeriform fluids, which he calls *gases*, a term now in common use. He also speaks of a subtile invisible agent, called *Blas*, which, he says, is an etherial emanation from the heavenly bodies. "Winds are air agitated by the *Blas* of the stars."[1]

The doctrine of the Four Elements, as established by the ancient philosophers, underwent several alterations in the hands of the chemists of the sixteenth century. The former regarded Earth, Water, Air, and Fire, as the universal rudiments of all matter, and assigned to each its particular station in the universe. Earth tended towards the centre, water to the surface of the globe; air occupied a middle station between water and fire; which last was considered as the most rare, subtile, and active of all things; it was supposed to constitute the heavenly bodies, and to confer life and action upon the other principles, to various combinations of which the different productions of nature were referred.

Basil Valentine, Paracelsus, and Van Helmont, speak of Salt, Sulphur, and Mercury, as the elementary principles of bodies; but the passages in their works referring to this hypothesis, are too dark and absurd to merit quotation; it was, however, adopted by several of their contemporaries and successors.

[1] "Nescivit inquam schola Galenica hactenus differentiam inter gas ventosum, quod mere aer est, id est, ventus per siderum blas commotus, gas pingue, gas siccum, quod sublimatum dicitur, gas fuliginosum sive endemicum, et gas silvestre sive incoercibile, quod in corpus non cogi potest visibile." (*Oper. om.* p. 399.

During the sixteenth century, some progress was made in the elucidation of the chemical arts, especially of Metallurgy, upon which subject the works of Agricola,[1] and of Lazarus Erckern, merit particular notice. The former has detailed, at considerable length, the various operations employed in mining, and his descriptions are at once correct and elegant; but his attempts at theory are deeply tinctured with the prevailing follies of the age. Agricola, who died at Chemnitz in 1555, was succeeded by Erckern, superintendant-general of the German mines; "he is an experienced, candid, and honest writer, relates nothing but what he had himself seen, without a word of theory or reasoning, and every where speaks as if he were sitting before the furnace and relating what passed."[2]

After wading through the thick fog of alchemical speculation, which envelopes the writers of this period, it is a relief to meet with one whose details are thus intelligible, and who adheres to matter of fact.

The periods we have now considered, teemed with searchers for the philosophers stone,—the elixir of life,—and the universal medicine. Of these such have hitherto only been noticed, as conduced, by their experiments and discoveries, to the progress of chemical science.

[1] The mineralogical works of Agricola display very minute information upon the most important parts of his subject. They are, 1. *De ortu et causis subterraneorum.* 2. *De natura eorum quae effluunt ex terrà.* 3. *De natura Fossilium.* 5. *De medicatis fontibus.* 6. *De subterraneis animantibus.* 7. *De veteribus et novis metallis.* 8. *De re metallica.* This last has passed through several editions, and is an excellent compendium of what was then known upon the theory and practice of the miners art, and of the working of metals.

[2] "Liber ejus (Lazer. Erckern), in folio, est editus linguâ Teutonicâ. pollicem crassus et iterum recusus est in Germana, in 4to. Est auctor in hac parte optimus." (Boerhaave.)

The records of the fifteenth and sixteenth centuries present a motley group of these adventurers solely devoted to the occult art of transmutation. Some were open impostors; others deluded believers; but their respective histories are, in general, so similar, that an account of one will suffice:[1] Bernard Trevisan, who was born at Paris early in the fifteenth century, and who suffered severely under this intellectual epidemick, may be cited for the purpose. He commenced his career with the unsuccessful repetition of certain processes of transmutation described by Rhazes, in which he expended eight hundred crowns. The perusal of Geber's treatise on the perfection of the metals rekindled his hopes, and, after wasting two thousand crowns upon apparatus and materials, this experiment proved as fruitless as the former. The writings of Ruspescissa, Archelaus, and Sacrobosca, shortly afterwards engaged his notice; and, to ensure success, he associated himself with a monk, and performed a variety of silly but laborious experiments, at the expense of more than a thousand crowns. He submitted the same portion of spirit of wine to three hundred

[1] Among the English alchemists, we may enumerate George Ripley, who, in 1471, wrote the *Compound of Alchemie*, dedicated to Edward IV.; and the celebrated Elias Ashmole, who called himself *Mercuriophilus Anglicus*, and who published and edited many treatises on alchemy. He founded the Ashmolean Museum at Oxford in 1679. The reader, who may wish to amuse himself with the nonsense of our own alchemists, is referred to the *Theatrum Chemicum Britannicum, containing severall poeticall pieces of our famous English philosophers who have written the Hermetique mysteries in their owne antient language. By* Elias Ashmole. Esq. *Qui est Mercuriophilus Anglicus;* and to the celebrated alchemical work *Philalethes*.

The following act of parliament, which Lord Coke calls the shortest he ever met with, was passed in the fifth year of Henry IV.: "None from henceforth shall use to multiply gold or silver, or use the craft of multiplications, and if any the same do, he shall incur the pain of felony." (Watson's *Chemical Essays.*)

distillations, and was engaged during a period of twelve years, in a series of fruitless and unmeaning operations upon alum, common salt, and copperas. At length he quitted his native country for Italy ; thence he proceeded to Spain and Turkey, in search of the adepts of the art, from whom he hoped to acquire the secret, and reimburse himself. Thus having squandered the scanty remains of his broken fortune, and reduced nearly to beggary, he retired to the isle of Rhodes, where he entered the service of Arnold of Villa Nova, from whom he states that he obtained that which he so long searched for. So true is that definition of Alchemy, which describes it as an art without principle, which begins in falsehood, proceeds in labour, and ends in beggary.

Entering upon the seventeenth century, the historian of Experimental Science must ever pause to pay a tribute of gratitude and respect to the celebrated Francis Bacon ; a man whose faults as a statesman have been eclipsed to the eyes of posterity, by the brilliancy and excellence of his philosophical character.

It may commonly be observed, that those who are gifted by nature with superiour genius or uncommon capacity,—who are destined to reach the meridian of science, or to attain exalted stations in the learned professions, have exhibited early symptoms of future greatness ; either indefatigable industry, or extraordinary sagacity, or ardent enthusiasm, have marked their entrance into the affairs of life. At the age of sixteen, Bacon was distinguished at Cambridge ; and, very shortly afterwards, struck with the frivolous subtilty of the tenets of Aristotle, he appears to have turned his mind into that channel, which led on to future eminence. The solid foundation of his scientifick character is the *Instauration of the Sciences*. It opens with a general and philosophical survey of the subject ; whence he pro-

ceeds to infer the futility of the ancient philosophical systems, and to point out Induction, from sober and severe experiments, as the only road to truth. Pursue this, he says, and we shall obtain new powers over nature; we shall perform works as much greater than were supposed practicable by natural magick, as the real actions of a Caesar surpassed the fictitious ones of a hero of romance.

Speculative philosophy he likens to the lark, who brings no returns from his elevated flights; experimental philosophy to the falcon, who soars as high, and returns the possessor of his prey.

Illustrations of the new method of philosophizing, and the mode of arranging results, conclude this admirable and unrivalled performance.

To do justice to this work, we must, for a moment, forget the present healthy and vigorous constitution of science, and view it deformed and sickly in the reign of Elizabeth. We shall then not be surprised at the irrelative observations and credulous details, which occasionally blemish this masterly production of the human mind.

But the history of Lord Bacon furnishes other materials for reflection. Upon the accession of James I., he became successively possessed of the highest honours of the law, and acquired great celebrity as a publick speaker and a man of business; yet, amidst the harassing duties of his laborious avocations, he still found time to cultivate and adorn the paths of science, the pursuit of which furnished employment for his scanty leisure, and relaxation in his professional toils; and, when ultimately disgraced, "his genius, yet unbroken, supported itself amidst involved circumstances and a depressed spirit, and shone out in literary productions." Nor should the munificence of his royal master remain unmentioned, who, after remitting his fine, and releasing him from his prison in the Tower, conferred on him a large pen-

sion, and used every expedient to alleviate the burden of his age, and to blunt the poignancy of his sufferings.

After the death of Lord Bacon, which happened in April 1626, in the 66th year of his age, the records of science began to assume a brighter aspect; and we discern true knowledge emerging from the dungeons of scholastick controversy, and shaking off the shackles of polemical learning.

The philosophers by fire, as the Chemists were emphatically termed, no longer exclusively engaged in seeking for the elixir of life, and the stone of transmutation, began to direct their endeavours towards more attainable and useful objects. They availed themselves of the accumulated facts collected by the misguided zeal and barren labours of their predecessors, and combined these useless and unseemly materials into the foundations of a beautiful and useful department of knowledge; but their progress was slow, and not unfrequently interrupted by relapse into the follies of Alchemy.

Glauber of Amsterdam,[1] and in this country, the Honourable Robert Boyle, are characteristick writers of the middle of the seventeenth century. The former has detailed many curious and interesting facts respecting neutral salts, acids, and animal and vegetable substances; but his descriptions are darkened by the language of the adepts, and valuable truths are disguised by being blended with the unintelligible jargon of the black art.

The perusal of Glauber's chemical works leads to some surprise at the multitude of facts with which he was acquainted, and, among them, we meet with discoveries which have been considered of modern date. He particularly

[1] A collection of Glauber's works, in Latin, was published at Frankfort, in 1658, in 8vo, and in 1659 in 4to. An English translation was published at London, in 1689, by C. Pack.

describes the production of vinegar during the destructive distillation of wood. (*Miraculum Mundi*, p. 1.) The following may be selected from among many similar passages in his writings, as exhibiting the active and original turn of mind of this keen and curious inquirer, and as containing the germ of many truths which have been more fully developed in our own time.

"But what other things the said juice of wood is able to effect, we cannot here declare, by reason of our intended brevity; yet this I will add, that, if this acid spirit be rectified, it may be used in the preparation of good medicines; in mechanick arts; in the making of many fair colours from the extraction of metals, minerals, and stones; and for all things for which common vinegar is used; yea, far more commodiously, because it much exceedeth common wine and beer vinegar in sharpness."

He also mentions the tar produced in the same process, which he recommends as efficacious in preserving wood that is exposed to weather, and speaks of it, when mixed with ashes, as a profitable and quickly acting manure. He further points out the method of concentrating the vinegar of wood by exposure to cold, "which freezes the phlegm only, but the sharp spirit is not turned into ice, but remaineth in the middle of the hogshead, so sharp that it corrodeth metals like aqua-fortis. If hop-poles be dipped in the oil, it not only preserves them, but fattens the plant; and as insects abhor these hot oils, if they be applied to the bark of fruit trees, it will defend them from spiders, ants, cankerworms, and other insects; by this means also, rats and mice may be prevented from creeping up hovel posts, and devouring the grain." Glauber details a number of experiments relating to the action of this vinegar of wood, on limestone, and notices the use of its compounds; and that he was accurately acquainted with its superiour acidity, ap-

pears from the following quotation: "It is said that Hannibal made a passage through the Alps for himself and his army, softening the rocks by the benefit of vinegar. What vinegar that was, histories do not mention. Perhaps it was the vinegar of wine; but if he had had the vinegar of wood, he might sooner have attained his desire."

These shrewd remarks and useful observations are thickly scattered through the verbose pages of Glauber. He enriched the laboratory with new agents, and into medicine he introduced several new and useful remedies. Upon the arts he bestowed many improvements, and was among the first who seriously endeavoured to benefit agriculture by the medium of experimental chemistry.

Boyle[1] has left voluminous proofs of his attachment to scientifick pursuits, but his experiments are too miscellaneous and desultory to have afforded either brilliant or useful results; his reasoning is seldom satisfactory; and a broad vein of prolixity traverses his philosophical works. He was too fond of mechanical philosophy to shine in Chemistry, and gave too much time and attention to theological and metaphysical controversy to attain any excellence in either of the former studies. He who would do justice to Boyle's scientific character, must found it rather upon the indirect benefits which he conferred, than upon any immediate aid which he lent to science. He exhibited a variety of experiments in publick, which kindled the zeal of others more capable than himself. He was always open to conviction; and courted opposition and controversy, upon the principle that truth is often elicited by the conflict of opinions. His

[1] Boyle was born in January 1627, at Lismore, in the province of Munster, in Ireland. He was educated at Eton, and afterwards travelled in Italy, Switzerland, and France, and returned to England in 1644. In 1668 he took up his residence in London; and in 1680 was elected President of the Royal Society. He died on the 30th of December 1691, aged 65.

disposition was ever amiable, mild, and generous, and he was at once the patron of learning and of virtue.

The merit of bringing Hooke[1] before the publick, and of pointing out to him the road to eminence, is chiefly due to Mr. Boyle, who, in the troublesome and bigotted periods of the commonwealth and protectorship, associated himself with a few philosophical friends at Oxford, for the purpose of promoting experimental inquiry. Hooke, who enjoyed the advantage of having been educated at Westminster school, under Dr. Busby, was introduced in the year 1655 to this select society, where his original and inventive genius was soon discerned and called into action. Boyle engaged him as his operator and assistant, and his talents were turned with great success, to the invention and improvement of philosophical instruments, and to many important subjects connected with the mechanical arts.

It was about this period that the physical properties of the atmosphere began to attract notice, and that the favourite scholastick notion of Nature's abhorrence of a vacuum was called into question. Galileo was, perhaps, the first

[1] Sir Godfrey Copley, in a letter written about the time of Hooke's death, says, " Dr. Hooke is very crazy; much concerned for fear he should outlive his estate. He hath starved one old woman already, and, I believe, he will endanger himself to save sixpence for any thing he wants." In another, written a few weeks after his death, Sir Godfrey says, " I wonder old Dr. Hooke did not choose rather to leave his 12,000*l.* to continue what he had promoted and studied all the days of his life,—I mean mathematical experiments, than to have it go to those whom he never saw nor cared for. It is rare that virtuosos die rich, and it is pity they should, if they were like him." (*Dr. Ducarrel's MSS.* quoted in *Biog. Dict.*) Hooke sometimes declared, that he intended to dispose of his estate for the advancement of natural knowledge, and to promote the ends for which the Royal Society was instituted; to build a handsome edifice for the Society's use, with a library, laboratory, and repository, and to endow a professorship. (*Life by Waller.*)

who broke this spell of Aristotelian philosophy; and in the year 1644, the grand discovery of atmospherick pressure, and its variation, was announced by Torricelli, the celebrated inventor of the barometer.[1] The idea of construcling a machine for the purpose of rarefying air, first occurred to Otto Guericke, who, after many fruitless attempts, succeeded by means of a sucking pump, in withdrawing a considerable portion of air from the interiour of a copper ball. With this awkward and imperfect air-pump, he performed several notable experiments. One of these is often exhibited at the present day. It consists in exhausting a hollow brass globe, composed of two hemispheres, closely fitted to each other. When a portion of the interiour air is removed, the pressure of the exteriour atmosphere is such, as to resist considerable force applied to separate the hemispheres. This is called the Magdeburgh experiment, and was first publickly exhibited in the year 1654 before the deputies of the empire, and foreign ministers assembled at the diet of Ratisbon. This original air-pump, invented by the Burgomaster of Magdeburgh, was greatly improved by Hooke, who, in conjunction with Boyle, performed by its means a variety of new and important experiments, illustrative of the mechanical properties of the atmosphere, which, at a subsequent period,

[1] The Peripateticks maintained, that the creation of a vacuum was impossible, even to supernatural power. This dogma was first shaken by a circumstance which happened to some workmen employed by the Grand Duke of Tuscany. Having sunk a deep well, they endeavoured to bring the water to the surface by a common sucking pump, but found, to their surprise, that they could only make it ascend to the height of about 30 feet. Galileo, whose talents had gained him great celebrity and respect, was consulted in this emergency. His answer was, that, although nature does dislike a vacuum, there is a certain limit to her antipathy, equivalent to the pressure of a column of water eighteen palms high.

tended considerably to the progress of pneumatick chemistry.

The works of Hooke, chiefly interesting to the chemist, are his *Micrographia* and *Lampas*, the former published in 1664, the latter in 1677. They contain anticipations of many of the subsequent changes and improvements of chemical theory, which will be noticed in a future page of this history.

Both the private and publick character of Dr. Hooke exhibit many faults, and are stained with many blemishes. His temper was peevish, reserved, and mistrustful; and he wanted that candour and dignity of mind which should raise the philosopher above the level of ordinary men. He was born at Freshwater, in the Isle of Wight, in 1635, and died in London in the year 1702.

Immediately after the Restoration, the gentlemen who formed the Philosophical Society at Oxford adjourned to London, where they held their meetings in Gresham College, and considerably extended the number of their members. The King, who himself loved science, countenanced and patronized their proceedings; and, on the 15th of July 1662, granted a royal charter, constituting them a body corporate, under the name of *The Royal Society of London, for promoting Natural Knowledge.* In the year 1665 was published the first number of the *Philosophical Transactions*, of which work, justly regarded as the standard of English science, a volume has been published annually since the year 1762.

This laudable and rare example of Charles the Second was followed by Lewis the Fourteenth of France; and in the year 1666 the *Royal Academy of Sciences* was instituted at Paris, under the immediate protection of that monarch. Neither was the patronage cold, nor the honours empty, which were bestowed by Lewis on the fol-

lowers of science. Salaries he conferred upon scientifick bodies, and pensions upon learned men, "a generosity," says Hume, "which does great honour to his memory, and in the eyes of all the ingenious part of mankind will be esteemed an atonement for many of the errours of his reign. We may be surprised," continues the historian, "that this example should not be more followed by Princes, since it is certain that bounty so extensive, so beneficial, and so much celebrated, cost not this monarch so great a sum as is often conferred upon one useless overgrown favourite or courtier." Happily for the scientifick character of Britain, the genius, talents, and exertions of individuals have ever been sufficient to counterbalance such advantages; and thus nurtured and protected, the growth of science has not been less rapid or vigorous than where she has enjoyed the sunshine of royal favour.

With the great and unrivalled name of Newton, we close the records of the seventeenth century. To him Chemistry is indebted for the first correct views respecting the nature of combination; a subject which had little engaged the attention of the more sensible experimentalists of the preceding periods, and which was formerly attributed to the occult qualities of the Aristotelians, and afterwards to the mechanical forms of the particles of bodies.[1]

Chemical affinity was referred by Newton to the different attractive powers of the different kinds of matter in regard to each other. Salt of tartar becomes moist by exposure to air, because that salt attracts the humidity of the atmosphere. Muriatick acid unites with salt of tartar by virtue of their respective attractions; but when oil of

[1] We shall again have occasion to refer to certain chemical opinions of Newton. In the present instance, reference is made to the thirty-first query annexed to the *Third Book of Opticks*. (Newton, *Opera Omnia*, 4to, Lond. 1782.)

vitriol is poured upon this compound, the former acid is displaced by the superiour attraction of the latter. Silver dissolved in aqua-fortis is separated from that menstruum by the superiour attraction of quicksilver; in like manner copper separates quicksilver; and iron, copper. Referring to these and other similar instances, "does not this" says he "argue, that the acid particles of the aqua-fortis are attracted more strongly by iron than by copper, by copper than by quicksilver, and by quicksilver than by silver?" Such are the simple but clear, and, in most instances, correct suggestions, relating to the subject of attraction, which Chemistry owes to the great luminary of Mechanical Philosophy.

In tracing the history of Chemistry from early times, through the dark ages, to the beginning of the last century, I have noticed only such authors as conduced by the weight or novelty of their writings, the importance of their discoveries, or the example of their zeal, to the more immediate progress and elucidation of this department of philosophy. The annals of a period so extensive must necessarily record a host of experimentalists, to whose researches it would upon the one hand be impossible to do justice; and whose names, on the other, it would be useless to repeat. It may however be remarked, that alembicks, and other complex distillatory apparatus, were employed by the alchemical physicians who flourished between the ninth and thirteenth centuries. Mesue mentions the distillation of rose-water, and the production of spirit of wine is noticed by Raymond Lully. At this time, too, furnaces of peculiar construction, and a variety of complex apparatus and accoutrements, were introduced into the laboratory.

During the fifteenth and sixteenth centuries, Alchemy was at its acmé, and many were the unwary and avaricious

who were entrapped by the golden prospects and plausible mysticism of the art. Among them was that admirable artist Mazzuoli of Parma, better known under the name of Parmagiano.

Curious discoveries and useful inventions multiplied rapidly during the seventeenth century. Kunckel, in Saxony, successfully promoted the Chemistry of the Arts. In 1669, Brandt of Berlin discovered Phosphorus, and about the same time Homberg accidentally produced a spontaneously inflammable compound, which he called Pyrophorus. In 1674 the elder Lemery acquired great and deserved fame at Paris as a chemical lecturer. He was the first who threw aside the affected and pompous diction habitually indulged in by his predecessors and contemporaries, and adopted a simple and perspicuous style, which at once tended to the ready diffusion of his subject, and to its permanent popularity. When he published his course, "it sold" says Fontenelle "like a novel or a satire."

The establishment of literary and scientifick societies during this age was another grand step towards the promotion of knowledge, and the period was particularly propitious to their progress. Bacon, Galileo, and Kepler, had opened that road to truth which was so eagerly and successfully pursued by Boyle, Hooke, and Mayow, in this country, and in which the miraculous mind of Newton displayed its brilliant powers. In Germany, Beccher and Stahl are entitled to particular mention. The suggestions of the former, who was a man of an acute and inquisitive turn of mind, led the latter into that train of speculation which terminated in producing the Phlogistick Theory, and which will presently be more particularly considered. Homberg, Geoffroy, and the two Lemerys, were zealous followers of experimental chemistry in France, at the

establishment of the Royal Academy of Sciences. In short, the independent zeal and healthy activity in scientifick pursuit, which has since marked its progress in Europe, became manifest early in the seventeenth century; and the causes I have attempted to unfold contributed to the splendour which it began to acquire about the end of that important era in the general history of the world. The clouds of ignorance and errour quickly dispersed before this happy dawn of true knowledge; and science, no longer enveloped in scholastick mystery and absurd speculation, began to display those inherent charms, which gained her the courtship and admiration of every liberal and cultivated mind, and which laid the foundation of that extended dominion which she acquired in the succeeding age.[1]

SECTION II.

STATE OF CHEMISTRY AT THE OPENING OF THE EIGHTEENTH CENTURY.—OPINIONS OF BECCHER AND STAHL RESPECTING THE PHENOMENA OF COMBUSTION, COMPARED WITH THE VIEWS OF REY AND MAYOW.—PNEUMATICK CHEMISTRY OF HAILES AND BOERHAAVE.—INVENTION OF THE THERMOMETER.

The history of the progress of Chemistry during the seventeenth century presents many active and able inquirers, whose researches tended to develope new properties and combinations of bodies; but their attempts at theory

[1] Those who are desirous of consulting the alchemical authors, and of becoming particularly acquainted with the titles of their voluminous productions, will find a curious body of information on these subjects in the *Histoire de la Philosophie Hermetique*, Paris, 1742.—Gobet's *Anciens Mineralogistes*, published at Paris in 1779, gives some details of the early progress of Mineralogical Chemistry in France.

and generalization were, with few exceptions, absurd and abortive. They consisted in wild hypothesis and vague speculation, and were founded, not upon the sober and steady basis of truth, but upon the unreal and tottering visions of the imagination. The spirit of Lord Bacon was slow in animating experimental philosophy, until Newton rose to surprise and illumine the world. It then assumed a new and cheerful aspect, and quick was its growth, and illustrious its progress, under the invigorating influence of that sun of science.

Although Chemistry does not lie under the same weighty obligations to Newton as mechanical philosophy, he conferred upon it a great and lasting benefit, by the disclosure of those clear and simple views which have already been alluded to.[1] The important deductions, too, which flow in

[1] The following passages, in addition to the previous observations in the text, will be sufficient in illustration of Newton's views of *Elective Attractions*.

"Have not the small particles of bodies certain powers, virtues, or forces, by which they act at a distance, not only upon the rays of light, for reflecting, refracting, and inflecting them, but also upon one another, for producing a great part of the phenomena of nature? for, it is well known, that bodies act one upon another by the attractions of gravity, magnetism, and electricity; and these instances show the tenor and course of nature, and make it not improbable that there may be more attractive powers than these. For nature is very consonant and conformable to herself. How these attractions may be performed I do not here consider; what I call attraction may be performed by impulse, or by some other means unknown to me. I use that word here to signify only, in general, any force by which bodies tend towards one another, whatsoever be the cause. For we must learn from the phenomena of nature, what bodies attract one another, and what are the laws and properties of the attraction, before we inquire the cause by which the attraction is performed. The attraction of gravity, magnetism, and electricity, reach to very sensible distances, and so have been observed by vulgar eyes, and there may be others which reach to so small distances as hitherto escape observation, and perhaps electrical attraction may reach to such small distances even

easy perspicuity from his experimental researches, soon became general models of imitation; and the new style which we discern in the philosophical authors of the early part of the eighteenth century throughout Europe, may, in a great measure, be referred to the lofty example before us.

No sooner was the spell of Alchemy broken, than the phenomena of combustion began to attract the notice of the

without being excited by friction. For, when salt of tartar runs *per deliquium*, is not this done by an attraction between the particles of the salt of tartar and the particles of the water which float in the air in the form of vapours? And why does not common salt, or saltpetre, or vitriol, run *per deliquium*, but for want of such an attraction? Or why does not salt of tartar draw more water out of the air than in a certain proportion to its quantity, but for want of an attractive force after it is satiated with water? And whence is it but from this attractive power that water, which alone distils with a gentle and lukewarm heat, will not distil from salt of tartar, without a great heat? And is it not from the like attractive power, between the particles of oil of vitriol and the particles of water, that oil of vitriol draws to it a good quantity of water out of the air; and, after it is satiated, draws no more, and in distillation lets go the water very difficultly? And when the water and oil of vitriol, poured successively into the same vessel, grow very hot in the mixing, does not this argue a great motion in the parts of the liquors? And does not this motion argue that the parts of the two liquors, in mixing, coalesce with violence, and, by consequence, rush towards one another with an accelerated motion? And when *aqua-fortis*, or spirit of vitriol, poured upon filings of iron, dissolves the filings with a great heat and ebullition, is not this heat and ebullition effected by a violent motion of the parts?" &c. "When spirit of vitriol, poured upon common salt or saltpetre, makes an ebullition with the salt, and unites with it, and, in distillation, the spirit of the common salt or saltpetre comes over much easier than it would do before, and the acid part of the spirit of vitriol stays behind;—does not this argue that the fixed alcaly of the salt attracts the acid spirit of the vitriol, more strongly than its own spirit; and, not being able to hold them both, lets go its own?"—Newton's *Opticks*, Opera omnia, 4to, Lond. 1782.

early chemical theorists. The influence of the air upon this process had been long observed, and many of the changes suffered by the combustible, had been examined with a surprising degree of acuteness and precision; for fire was almost the only agent employed at that period to effect combination and decomposition. These inquiries constitute a prominent feature in the history of Chemistry. It may therefore be requisite to pursue them with a minute attention, which may at first appear tedious, but which will gain in importance and interest as they proceed.

The first speculations in theoretical Chemistry deserving attention, are those of John Joachim Beccher of Spires, who died in England in 1685. He gained considerable celebrity at Vienna and Haerlem, for improvements in arts and manufactures, but was induced to retire to this country, in consequence of the jealousy of rivals, and the neglect of those upon whom he had conferred benefits. His works abound in shrewd and witty remarks, and in deep and curious reasoning,—in frivolous subtilty, and in weighty and sensible observations. His hypothesis respecting the origin of the varieties of matter, from the mutual agencies and combinations of a few elementary principles, though unnecessarily blended with scriptural history, are characterized by considerable brilliancy of thought and originality of invention. They are detailed at great length in his *Physica Subterranea*, which treats on the original creation of matter, and the transition and interchange of elements. The *Institutiones Chemicae*, or *Œdipus Chemicus*, of this author, is another curious production, containing the history of the chemical elements, and describing the leading operations of the laboratory. Earth was the favourite element of this philosopher, of which he supposed three varieties to exist, namely, a vitrifiable, a metallick, and an inflammable

earth. Of these the various productions of nature were formed.[1]

But the most celebrated chemical theorist of the latter part of the seventeenth century is Ernest Stahl, born at Anspach in Franconia, in 1660. He adopted many of the opinions of Beccher respecting the cause of inflammability, and upon these foundations reared the celebrated System of Phlogiston, according to which, inflammability is supposed to depend upon the presence of a highly subtile and elastick matter, which, at certain temperatures, is thrown into violent motion, and appears under the form of flame or fire. Combustion is the separation of this principle, and bodies contain it in various proportions. Charcoal, for instance, when burned, leaves scarcely any residuum, and is, therefore, nearly pure phlogiston. Antimony, when burn-

[1] Beccher wrote voluminously upon a great variety of subjects. His principal chemical works are as follows.

1. *Oedipus Chemicus.* 2. *Metallurgia, de generatione, refinatione, et perfectione Metallorum.* 3. *Physica Subterranea*, and its various appendices. 4. *Parnassus Medicinalis Illustratus.* 5. *Laboratorium Portabile.* 6. *Chymischer Rosen-garten.*

Beccher's *Oedipus* is dedicated to Francis Sylvius Deleböe, who, in 1658, was elected the first Professor of Medicine in the University of Leyden. He was a man of an acute mind, as appears from his various essays and tracts, more especially from his *Praxeos Med. Idea Nova.* He died at Leydon in 1672. "Utilissimum profecto munus subiisti, quo tui auditores non verba sed corpora, non chymerasticos terminos, verum ipsas reales enchyrises, non inanes denique et immateriales facultates, sed a te demonstrati, effectus causas practicas audiunt, vident, tangunt." Beccher every where compliments him as a man not of words, but of deeds; as a philosopher, who eminently sought to render science popular and intelligible to all capacities.

The language of Beccher's *Physica Subterranea* is sufficiently inelegant and incorrect. "Excuso *Latinitatem* in hoc opere," says he, "quam *barbaram* esse fateor, ob materiem et ob scriptionem, in specie scriptionis modum: ex ore enim dictantis totum opus conceptum est. Sic *rebus* attentus, *verba* neglexi." This is at once an example and apology.

ed, affords a large proportion of earthy matter. If this earth be heated with charcoal, or other matter abounding in phlogiston, antimony is regenerated; this metal, therefore, is a compound of earth and phlogiston.

If sulphurick acid, which is not inflammable, be distilled with oil of turpentine, which is extremely so; or, in other words, if phlogiston be added to sulphurick acid, sulphur is obtained. Sulphur, therefore, is a compound body, consisting of sulphurick acid and phlogiston. If sulphur and common soda be fused together, a brown compound is obtained, formerly called liver of sulphur, and the same product results when charcoal is heated with Glauber's salt, which consists of soda combined with sulphurick acid. Such was Stahl's explanation of the phenomena of combustion, and such the apparently plausible experimental proofs upon which it was founded.[1]

In Germany and in France, the phlogistick doctrine was received with that thoughtless and eager enthusiasm which suffers the blaze of novelty to eclipse the steady light of truth, and which is rather captivated by plausible exteriour than by internal excellence. Even in this country the experiments of Boyle and of Hooke, if not forgotten, were over-looked, and hypothesis for a time gained the ascen-

[1] Stahl's doctrines are very ably set forth in his *Three Hundred Experiments*, published at Berlin in 1731; and in his *Fundamenta Chemiae*, Nuremberg, 1723 and 1732. He observed the necessity of air to combustion, and considered flame or fire as resulting from its violent etherial agitations. Stahl is continually urging circumspection in hypotheses, yet preconceived opinions are always leading him to erroneous conclusions, as the following passages amply prove. "Aer ignis est anima, hinc, sine aere nihil potest accendi vel inflammari."—Aer in motum excitatus, seu ventus artificialis, vel etiam naturalis, mirum excitat motum aetheris, seu flammam; hinc ad ignem fusorium, et vitrificatorium, promovendum, follibus opus est; imo gradus et vehementia ignis dependet multum ex aeris admissione." *Fund. Chem. dogmat. et ration.* p. 22.

dancy over facts; for it had been most satisfactorily demonstrated by those experimentalists, that bodies will not burn if air be excluded, and that, during combustion, a portion of the air is consumed by the burning body. Even at an earlier period, the same observation had been most pointedly dwelt upon, and another equally important circumstance ascertained, namely, the increase of weight sustained by metals during their calcination. As early as 1629, Brun, an Apothecary, resident in the town of Bergerac in France, melted two pounds six ounces of tin, and in six hours the whole was converted into a calx, which weighed seven ounces more than the tin employed. Brun, surprised at this circumstance, communicated it to John Rey,[1] a physician of Perigord, who, in 1630, published a Tract upon the subject, in which he refers the increase of weight to the absorption and solidification of air: "Thus," says Rey, in the fanciful language of the period, "have I succeeded in liberating this surprising truth from the dark dungeons of obscurity; which was vainly but laboriously sought after by Cardan, Scaliger, Faschius, Caesalpinus, and Libavius. Others may search for it, but in vain, unless they pursue the royal road which I have cleared. The labour has been mine,—the profit is the reader's,—the glory is from above."

But amongst the authors whose researches tended to conclusions diametrically opposite to those of Stahl and his associates, and whose writings abound in anticipations of

[1] *Essays* de Jean Rey, Docteur en Medecine, *sur la Recherche de la Cause pour laquelle l'Estain et le Plomb augmentent de poids quand on les calcine.*" Paris, 1777.

Of these curious essays, originally printed in 1630, a copy was discovered in the Royal Library at Paris in 1776. The scarcity of the first edition is in some measure accounted for in the "Advertisement" to the present, but the rarity of this reprint is very enigmatical.

modern discoveries, no one stands so conspicuous as our countryman John Mayow.[1] His tracts, published at Oxford in 1674, relating to chemical, physiological, and medical subjects, abound in traits of original and inventive genius, and furnish the prototype of many discoveries, which have conferred great and lasting renown upon succeeding labourers in the field of Chemistry. It is the treatise upon nitre and the nitro-aerial spirit to which I principally allude, and of which it may be proper to give a short but connected sketch.

The atmosphere, he observes, contains a certain nitro-saline matter, a spirit, vital, igneous, and fermentative, which exists in, and may be obtained from nitre; that it supports combustion, but is itself incombustible; that it exists in nitrick acid; that when antimony is exposed to the joint operation of heat and air, it imbibes the nitro-aerial particles, whence its increase in weight; and that a similar change may be effected by nitre or by nitrick acid; that acidity depends upon the absorption of the same principle which in sulphurick acid is combined with sulphur, either during combustion, or during the exposure of pyrites to air: that fermentation is referable to a very similar cause: that it is necessary to vegetation, and present in all cases of combustion; that it is absorbed by animals during respiration; and that the same substance which contributes to the support of flame, is likewise required for the support of life. Mayow also was acquainted with the

[1] Mayow was born in Cornwall in 1645, and died in London in 1679, at the early age of thirty-nine. Dr. Beddoes and Dr. Yeats have asserted Mayow's claims to several modern discoveries; and in many other instances than those quoted in the text, he has certainly anticipated both the discoveries and inventions of some of his chemical successors. All Mayow's tracts are deserving of attentive perusal and are of full knowledge. The first and second, *De Sal-nitro et Spirito Nitro-aerio* and *De Respiratione*, contain a vast body of chemical facts, resulting from well conceived and conducted experiments.

evolution of air during the action of nitrick and vitriolick acids upon iron, and points out a mode of collecting it, in bottles inverted iu vessels of the dilute acids. He observes that the air generated in these experiments, although expansible by heat, is probably different from the atmosphere, as is also the air which an animal has breathed, and in which a candle has burned.

These are a few of the important facts dwelt upon by Mayow, respecting the nature of the atmosphere, and of the cause of combustion. That they were not at the time opposed to the purely speculative notions of Stahl is truly remarkable, for they explain, in conjunction with the observations of Rey and others, the great obstacle to the phlogistick hypothesis, the increase of weight in the burning body; they show the real cause of the necessity of the presence of air, which, if combustion consisted in the mere evolution of the subtile principle of fire, could not be required; and they adduced experimental evidence, where Stahl merely surmised.

Another active inquirer occurs in this page of chemical history; one whose researches cleared the way for the great discoveries of the succeeding era, and to whom the merit is justly due of having opened a mine in the field of nature; who indulged, not in the speculative and metaphysical frivolities which characterize the productions of most of his predecessors, and many of his contemporaries, but followed nature with a steady and unerring step, and recorded his observations in a concise, unadorned and unaffected style. This was the Reverend Dr. Stephen Hales.[1] He was the first who instituted researches into

[1] Born in 1677; died in 1761. Dr. Hales is one of the few divines who have employed their abundant leisure in philosophical and experimental researches. It is said that he refused high preferment upon more than one occasion, in order that he might attend to his humble parochial duties, and continue his scientifick pursuits.

the physiology of vegetation, a subject which he pursued with considerable ardour and perseverance. He also made a variety of experiments upon the extrication of air during the exposure of animal, vegetable, and mineral substances to heat. In perusing his Essays on these subjects, we frequently find him upon the verge of those splendid discoveries which fell to the lot of his fellow-labourers and successors; but the erroneous nature of his preconceived opinions induced him to take for granted that which experiment should have determined, and to rest satisfied with results which, had they been followed up, would inevitably have led to the most important and novel facts. His experiments do credit to his industry, but his conclusions betray feebleness of judgment. If, instead of regarding the various gaseous products obtained from the substances he operated upon, as consisting of common air contaminated by their effluvia, he had submitted them to more close investigation, he would doubtless have run a more brilliant and successful career. He is justly regarded as the founder of Pneumatick Chemistry, but he contributed few materials to the superstructure.

Herman Boerhaave,[1] of Leyden, who was a contemporary of Hales, pursued a similar train of inquiries; but,

He directed his attention to the quantity of moisture imbibed and emitted by different plants, and to the circulation of the sap, which, he says, put him upon making a more particular inquiry into the nature of a fluid which is so absolutely necessary for the support of the life and growth of animals and vegetables. His *Specimen of an Attempt to analyse the Air by Chymiostatical Experiments* displays extraordinary ingenuity in the contrivance of experiments and apparatus. It was his misfortune to consider the various gases which he procured as mere modifications of atmospherick air. *Philos. Trans. Statical Essays*, London, 1731.

[1] Boerhaave was born in December 1668, at a village near Leyden. He died in September 1738. He was an eminent

although many of his experiments were new and well conceived, he was not more happy in his conclusions, nor more fortunate in his discoveries. He attributed the elasticity of air to its union with fire, and considered its ponderable matter as susceptible of chemical combinations; but the existence of different aeriform fluids escaped his notice.

ornament of medicine, as well as of chemical science. His oration upon resigning the office of Governour of the University of Leyden has been justly eulogised by Johnson. (*Life of Boerhaave.*) He here declares in the strongest terms (says his elegant biographer) in favour of experimental knowledge, and reflects with just severity upon those arrogant philosophers, who are too easily disgusted with the slow methods of obtaining true notions by frequent experiments, and who, possessed with too high an opinion of their own abilities, rather choose to consult their own imaginations than inquire into nature, and are better pleased with the charming amusement of forming hypotheses than the toilsome drudgery of making observations.

The emptiness and uncertainty of all those systems, whether venerable for their antiquity, or agreeable for their novelty, he has evidently shown; and not only declared, but proved, that we are entirely ignorant of the principles of things, and that all the knowledge we have is of such qualities alone as are discoverable by experience, or such as may be deduced from them by mathematical demonstration.

Boerhaave's contributions to physick were large and valuable. His principal chemical work is the *Elementa Chemiae*, of which a good translation, with notes, was edited in 1753 by Dr. Shaw. This work he dedicated to his brother, who was intended for the medical profession, but went into the church; while Boerhaave, who originally studied divinity, relinquished it for physick and chemistry. Alluding to this circumstance, "Providence," says he, "has changed our views, and consigned you to religious duties, while I, whose talents were unequal to higher objects, am humbly content with the profession of physick."

In the *Elementa*, and in several of his Orations, are admirable remarks upon the useful application of Chemistry to other branches of knowledge. His observations upon its usefulness and necessity to the medical practitioner, may be well enforced at the present day; for, excepting in the Schools of London and Edinburgh, Chemistry, as a branch of education, is either entirely neglected, or, what is perhaps worse, superficially and

The philosophers whose names have been now recorded, not only greatly added to the stock of chemical facts collected by their predecessors, but conferred new life and vigour upon the science by their occasional incursions into the regions of theory and rational speculation :—in this light, the works of Rey, Mayow, and Stahl, deserve particular attention; the two former for correctness and precision, the latter for boldness and ingenuity.

About this period the Thermometer was brought to perfection, which tended materially to the progress of that most refined and difficult branch of Chemical Philosophy, relating to the nature and effects of heat. The researches, on this subject, will presently form an important feature in our history, which renders it proper to notice this instrument of such consequence in their prosecution.

That bodies change in bulk, with variations of temperature, must have been noticed at a very early period; but there can be little doubt, that the idea of constructing an instrument for measuring these variations first occurred to Santorio,[1] Professor of Medicine, in the University of Padua, in the beginning of the seventeenth century; he is also celebrated for his Medico-statical experiments, which are well burlesqued in one of the early numbers of the *Spectator*.[2]

imperfectly taught. This is especially the case at the English Universities, and the London Pharmacopœia is a record of the want of chemical knowledge, where it is most imperiously required.

[1] Santorio was born in 1561 at Capo d'Istria, on the borders of the Gulf of Trieste. He died at Venice in 1636. His *Ars de Statica Medicina* was published at Venice in 1614. Much merit is due to the steady perseverance with which he opposed the occult remedies of the empiricks of his day.

[2] No. 25. By Addison.

Santorio's thermometer consisted of a tube, blown at one end into a bulb, and with the other open extremity immersed into water. In cold weather the confined air contracted and the water rose in the tube—in a warm atmosphere the air expanded and the fluid fell. Santorio observed some other particulars connected with the operation of this thermometer, among which the increased influence of the sun's rays, when the bulb was blackened, deserves notice.

The Academicians del Cimento, whose early labours have already been mentioned, materially altered and improved the thermometer, by employing a liquid to measure temperature, instead of air, the changes of bulk in which, in a moderate range of temperature, are so considerable as to render the instrument extremely bulky and otherwise inconvenient. They generally used spirit of wine, and fixed a scale of degrees to the tube, with a view to ascertain its variations in bulk with greater precision. These instruments soon acquired considerable celebrity, and were largely circulated under the appellation of the Florence Glass. In this state the uses of the thermometer were extremely limited, no two instruments corresponded, and there being a free communication between the fluid and the external air, it was liable to evaporation,—yet was this thermometer much preferable to the over-sensible and bulky instrument of Santorio. There was another objection to spirit of wine, arising out of the readiness with which it assumes an elastick state, and which renders it unfit for measuring temperatures even below the heat of boiling water. Sir Isaac Newton, therefore, suggested the use of linseed oil, which, however, is extremely ill adapted to the purpose, on account of its unctuosity, and the ease with which it solidifies. Quicksilver was first recom-

mended by Roemer,[1] the eminent Danish philosopher, who discovered the motion of light; it was also employed by Dr. Halley, and is now generally used. The advantages of this fluid metal in the construction of the thermometer are manifold; it retains its liquid state at very high and very low temperatures, and has the peculiar excellence of expanding very equally for equal increments of heat, which is far from the case with spirit of wine.

But the great improver of the thermometer was Fahrenheit,[2] a merchant of Dantzic, who, having failed in business, and being attached to chemical and mechanical pursuits, was obliged to gain a livelihood by making and selling these instruments. Fahrenheit used both spirit of wine and quicksilver, and hermetically sealed the tube containing the fluid; he also greatly improved the method of graduation, by establishing two points as the extremes of his scale, and subdividing the intermediate portion into a given number of degrees.

The division of the thermometrick scale had occupied the attention of several learned and ingenious men; but it was Fahrenheit who pointed out the most accurate means of accomplishing this purpose. The curious circumstance of the water running from melted snow being always of the same temperature, appears first to have occurred to Güricke of Magdeburgh, but was first applied to the graduation of thermometers by Sir Isaac Newton. Dr. Hooke had observed that the quicksilver in the tube of the thermometer, plunged into boiling-water, always rose to the same height; accordingly, if a mercurial thermometer be put into melting snow, and the point at which the

[1] Born at Arhusen in Jutland, in 1644,—died at Copenhagen in 1710.

[2] Born at Dantzic in 1686,—died in 1724.

fluid stands, marked upon the tube, and then transferred to boiling water, and that point also marked, and if the intermediate space be subdivided into any number of equal degrees, 100 for instance, it follows that, provided proper precautions have been taken in selecting and filling the tube, every thermometer, so constructed, will indicate the same degree, when applied to bodies of the same temperature. With regard to the boiling point, Fahrenheit observed it to differ under different degrees of atmospherick pressure, and pointed out the necessity of fixing it at a mean barometrical altitude. He had also noticed, that a degree of cold much more intense than that of ice might be procured by a mixture of snow and salt; and conceiving this to be extreme cold, he commenced his scale from that point, which is 32° below the freezing of water. Accordingly, Fahrenheit's scale commences at 0°, the temperature of his freezing mixture; the freezing point of water is marked 32°, and the boiling point 212°; the space between the freezing and boiling of water being divided into 180°. The graduation of thermometers received its greatest improvement in 1742, by Celsius of Sweden, who commenced the scale at the freezing of water, and divided the space between it and the boiling point into 100°. This is the centigrade scale, now used in France. Reaumur's scale, in which the point of congelation is marked 0°, and that of boiling-water 80°, is used in some parts of the European Continent; and in Russia the descending scale of Delisle is sometimes employed, in which the boiling point of water is 0°, the freezing 150°. These scales have each their merits and defects. In the event of innovation, the interval between the freezing and boiling of mercury, might be divided into 1000 equal parts; the former being 40° below 0° of Fahrenheit, the latter about + 670°. The degrees would thus be sufficiently small to be expressed without fractions; and the commencement of

the scale, which is about the lowest natural temperature, would be so low, as to preclude the frequent necessity of expressing negative degrees.[1]

From this sketch of the history of the thermometer, it is obvious, that its operation depends upon the circumstance of fluids diminishing in bulk by diminution of temperature, and the contrary; which is really the case with all fluids except water. This important fact was observed by the Florentine Academicians in their early experiments, and it is among the most curious and interesting discoveries of that zealous and active association of experimentalists. Having filled a large thermometer tube with water, they plunged it into a mixture of salt and snow. The water presently began to contract in bulk, and descend in the tube; but, instead of continuing to do so, till it reached the freezing point, after a short time it commenced expanding; the expansion went on till a portion of the water froze, and was then very suddenly increased.[2]

[1] This proposal is suggested by Mr. Murray. *System of Chemistry*, Vol. I.

[2] The following unaffected narrative of this celebrated experiment is very different from the usual verbose and pompous style of the philosophers of the period.

"Già sapevamo per innanzi (e lo sa ognuno) che il freddo da principio opera in tutti i liquori restrignimento, e diminuzione di mole, e di ciò non solamente n'avevamo la riprova ordinaria dell' aquarzente de' Termometri, ma n'avevamo fatta esperienza nell' acqua, nell' olio, nell' argentovivo, ed in molt' altri fluidi. Dall' altro canto sapevamo ancora, che nel passaggio, che fa l'acqua dall' esser semplicemente fredda al rimuoversi dalla sua fluidità, e ricever consistenza, e durezza coll' agghiacciamento non solo ritorna alla mole, ch' ell' aveva prima di raffreddarsi, ma trapassa ad una maggiore, mentre se le veggon rompere vasi di vetro, e di metallo con tanta forza. Ma qual poi si fosse il periodo di queste varie alterazioni, che in essa opera il freddo, questo non sapevamo ancora, ne era

The temperature at which water thus begins to expand by cooling is 40° Fahrenheit, and water cooled down to 32°, that is, 8° below 40°, occupies the same space as when heated to 8° above 40°; in other words, the density or specifick gravity of water is at its maximum at 40°.

When in the year 1683 Dr. Croune repeated this experiment before the Royal Society, Hooke attributed the effect, not to any peculiarity in expansibility of water, but to a rapid and sudden contraction of the glass bulb, which would force the water upwards in the tube;[1] a con-

possibile d'arrivarvi con agghiacciarla dentro a' vasi opachi, come quei d'argento, d'ottone, e d'oro'ne' quali s'era fin' allora agghiacciata: Onde per non mancare di quella notizia, che parea esser l'anima di tutte quest' esperienze, ricorremmo al cristallo, ed al vetro, sperando per la transparenza della materia d'aver presto ad' assicurarci come la cosa andasse, mentre si poteva a ciascun movimento, che fosse apparso nell' acqua del collo, cavar subito la palla dal' ghiaccio, e riconoscer in essa quali alterationi gli correspondessero. Ma la verità si è, che noi stentammo assai più che non ci saremmo mai dati ad intendere, prima di poter rinvenire alcuna cosa di certo intorno a' periodi di questi accidenti. E per dirne più distintamente, il successo è da sapere, che nella prima immersione, che facevamo della palla, subito, ch'ella toccava l'acqua del ghiaccio s'osservava nell' acqua del collo un piccolo sollevamento, ma assai veloce, dopo il quale con moto assai ordinato, e di mezzana velocità s'andava retirando verso la palla, finchè arrivata a un certo grado non proseguiva più oltre a discendere, ma si fermava quivi per qualche tempo, a giudizio degli occhi, offatto priva di movimento. Poi a poco a poco si vedea ricominciare a salire, ma con un moto tardissimo, e apparentemente equabile, dal quale senz' alcun proporzionale acceleramento spiccava in un subito un furiosissimo salto, nel qual tempo era impossibile tenele dietro coll' occhio, scorrendo con quell' impeto, per così dire, in istanti le decine e le decine de' gradi." *Esperienze intorno al progresso degli artifiziali agghiacciamenti, e de' loro mirabili accidenti.* Saggi di naturali esperienze fatte nell' accademia Del Cimento." Firenze, 1691.

[1] The *Histories of the Royal Society* by Sprat and Birch, contain a curious body of experimental evidence on a great varie-

clusion amply disproved by other forms of the experiment, especially by that suggested by Dr. Hope[1] of Edinburgh, in which a freezing mixture was applied to the surface of water at 60° contained in a tall cylindrical glass jar. The water was cooled throughout to 40°, and then the surface sunk to 32°, and froze. But when the freezing mix-

ty of philosophical subjects, and detail the opinions and observations of many emineut persons upon the various researches that were carried on before tbat learned body. The business of the Society was formerly conducted upon a very different plan from that now pursued, and much resembled the present proceedings of the Academy of Sciences of the Royal Institute of France.

The following is Dr. Birch's memorandum relating to this experiment:

February 6, 1683.

A letter of Mr. Musgrave to Mr. Aston, dated at New College, Oxford, was read, containing, among other things, several experiments about freezing, as that two inches of water in a tube $\frac{1}{2}$ inch diameter, expauded itself, upon freezing, $\frac{5}{6}$ higher; that a tube one inch diameter filled 6 inches, rose upon freezing, $\frac{7}{8}$ of an inch; and that half a pint of water, upon freezing, lost iu weight ʒij. ℈ij. gr. viij.

Dr. Croune said, that having weighed three ounces of water, he found it, after freezing, to differ a scruple and a half.

Sir Christopher Wren remarked, that if water were suddenly frozeu, there would be less differeuce in weight.

Dr. Croune said, that he observed water which he had put into a bolt-head, to rise higher before there was any thing of freezing in it.

Mr. Hooke attributed the rising of the water in the neck of the bolt-head, to the shrinking of the glass.

Dr. Croune said, that the glass had been long in the cold before, and that the water rose immediately.

Dr. Wallis proposed, that an empty glass might be cooled well in a freezing liquor, in order that it might have its contraction before the water be put into it.

This was done immediately by Mr. Hunt, and the water beiug put into a small bolt-head, rose about ** of an inch in the neck, though the air at that time was very warm. (Birch's *History of the Royal Society*. Vol. IV. p. 253.)

[1] *Edinburgh Transactions*, Vol. VI.

ture was applied to the bottom of the jar, the water became cooled throughout to 32°. If the cold be applied to the centre of the vessel, as long as the water is above 40°, the warmer part will always be at the top, but below 40° the arrangement is reversed, and the warmer part being then most dense, occupies the lower half of the vessel, and the colder portion floats upon it.

The influence of this singular anomaly, which has thus been demonstrated by unanswerable experiments, is of great extent and importance. In most of the cases in which nature deviates from her usual established laws, philosophy has discovered happy consequences in her aberration; and where such discovery has not been made, investigation should be upon the alert to trace the clue that is presented.

If water were obedient to the same laws of refrigeration as other less universal liquids, such as spirit, oils, and quicksilver, it must be evident, that, during the winter's cold, our rivers and lakes, instead of presenting a superficial stratum of ice, would soon become solid throughout; the continuous influence of the summer's sun would be required to produce their fluidity, and the inhabitants of the waters would annually risk extermination.

These effects are obviated by the peculiarity observed by the Academicians del Cimento. As the temperature of the earth is in winter always greater than that of the atmosphere, the cooling of large bodies of water must take place from above, by the contact of cold air and chilling blasts. The whole mass will thus be lowered to 40°, after which, the water becoming specifically lighter as it becomes colder, remains upon the surface where it sinks to 32°, and is converted into a film of ice, which being a bad conductor of heat, thickens slowly, and affords further protection to the warmer fluid beneath. Those

who in winter's cold accidentally fall through the ice, are surprised by the comparative warmth of the water below, and the aquatick animals that in summer sport upon the surface of their element, retire in winter to the more genial retreats which nature has thus provided.

In tracing the progress of Chemistry through its dark and early periods, the historian necessarily traverses a rugged and barren path; his chief object must be to advance, and the shortest is generally the safest road. Reaching the age of Alchemy, the prospect, though improved, is not such as to demand a very deliberate survey: its fictions, however, like those of romantick chivalry, have somewhat of reality for their basis, and by the mere increase of experimental inquiry, contributed essentially to the growth of chemical knowledge. As a science, its progress was languid until the middle of the seventeenth century, when it began to shake off the lethargy in which it had been sunk, and was turned with eager curiosity to new and more useful objects.

In the dross of the alchemical furnaces many scattered treasures were discovered, the value of which was greatly enhanced by arrangement and systematick combination. New views were thus opened to the Experimentalist; and authors, dismissing the florid exuberances and pompous affectation of their predecessors, cultivated an unadorned and simple style, more becoming the dignity of scientifick narration.

These circumstances contributed to confer a prosperous aspect on Chemical Philosophy at the commencement of the eighteenth century. It was applied to the arts, and to them it gave an unexpected and vigorous impulse. It was directed to the investigation of nature, and there it discovered new beauties. It found "tongues in trees, books in the running brooks, sermons in stones, and good in every thing."

SECTION III.

DISCOVERIES OF DR. BLACK, RELATING TO THE CAUSE OF CAUSTICITY IN EARTHS AND ALKALIES, AND TO CERTAIN PHENOMENA OF HEAT.

The discoveries of Dr. Joseph Black form a most important epoch in the history of Chemical Philosophy; they embrace two leading subjects,—the one relating to the causticity of the earths and alkalies—the other to the operation of heat in changing the state of bodies; in rendering solids liquid; and converting liquids into elastick or aeriform fluids.

Regarding these researches as isolated specimens of inductive philosophy, they have rarely been equalled: as influencing the progress of Chemistry, by disclosing the hidden cause of many very intricate phenomena, they have never been surpassed; and, by a happy combination of circumstances, we trace in them the distant but fertile source of those gigantick improvements of the arts, in which the perfection of the steam-engine is involved.

Of a man whose scientifick character is thus pre-eminent, and in whose attainments his country has just reason to exult, history has recorded a brief but interesting memorial.[1]

Dr. Joseph Black was sprung from a Scottish family, transplanted first to Ireland and then to France, where he was born in 1728, on the banks of the Garonne. When twelve years of age, he was sent for education to Belfast, and afterwards to the University of Glasgow, where he entered upon the study of physick, under the guidance of that bright ornament of medical science, Dr. William Cullen. In 1750, he removed to Edinburgh; four years af-

[1] Dr. Robison's Preface to Black's *Lectures on the Elements of Chemistry*.

terwards, he took the degree of Doctor of Physick; and, in 1756, published his Experiments on Magnesia, Quicklime, and some other alkaline substances, in the *Physical and Literary Essays.* In the same year, Dr. Cullen having removed to Edinburgh, Dr. Black returned to Glasgow to fill the Medical and Chemical chair of that University, where he was received with open arms both by the Classes and Professors. In 1764, he brought his ideas respecting the combinations of heat with ponderable matter to perfection. Speculations upon this subject had occupied his mind during a considerable period, but the difficulties of the inquiry, and the time necessarily consumed in other professional avocations, had considerably interfered with the pursuit.

In 1766, he was appointed to the Chemical Chair of Edinburgh, an office which he filled with such talent, industry, and perseverance, as not only drew an immense concourse of hearers to his class, but tended to confer upon chemistry a degree of popularity and importance, which has been greatly coudncive to its promotion and extension. "His discourse," says his biographer, Professor Robison, "was so plain and perspicuous, his illustrations by experiment so apposite, that his sentiments on any subject never could be mistaken; and his instructions were so clear of all hypothesis or conjecture, that the hearer rested on his conclusions with a confidence scarcely exceeded in matters of his own experience."[1] In short, Dr. Black, in his

[1] Dr. Black's character as a lecturer, is given by his friend Professor Robison in the following terms:—"He endeavoured every year to render his courses more plain and familiar, and to illustrate them by a greater variety of examples in the way of experiments. No man could perform these more neatly and successfully. They were always ingeniously and judiciously contrived, clearly establishing the point in view, and never more than sufficed for this purpose. While he scorned the

professorial capacity, was entitled to every praise, and he contributed most essentially to the foundation and increase of the reputation which the University of Edinburgh has acquired and maintained. Nor was his private character at variance with his publick excellence; he was mild, amiable, and fond of conversation, whether serious or sportive; and he was not above uniting to the highest philosophical attainments, most of the elegant accomplishments of life. In his advanced age he often expressed a hope that he might not linger in protracted sickness, on account of the distress which, in such cases, is suffered by attending friends; and his death, which happened in his 71st year, in November 1799, is on this account the more remarkable. He was taking some milk and water, and having the cup in his hand, when the last stroke of his pulse was to be given, had set it upon his knees, and in this attitude expired without the smallest agitation.

The writings of Black, though lamentably few, are masterpieces of scientifick composition. Newton was his model, and he was the first who transferred into chemistry the severe system of inductive logick, which marks the productions of that great master of natural philosophy.

quackery of a showman, the simplicity, neatness, and elegance with which they were performed, were truly admirable. Indeed, the *simplex munditiis* stamped every thiug that he did. I think it was the unperceived operation of this impression that made Dr. Black's lectures such a treat to all his scholars. They were not only instructed, but (they knew not how) delighted; and without any effort to please, but solely by the natural emanation of a gentle and elegant mind, co-operating indeed with a most perspicuous exhibition of his sentiments, Dr. Black became a favourite lecturer, and many were induced, by the report of his students, to attend his courses, without having any particular relish for chemical knowledge, but merely in order to be pleased. This, however, contributed greatly to the extending the knowledge of Chemistry, and it became a fashionable part of the accomplishments of a gentleman." *Preface*, p. li.

"In no scientifick inquiries, since the date of the *Principia* and *Opticks*, do we find so great a proportion of pure ratiocination, founded upon the description of common facts, but leading to the most unexpected and important results, as in the two grand systems of Black." Averse to all hypothesis, and aware of the multitudinous facts upon which a theory that is to stand firm must be founded, Dr. Black was unwarrantably slow in the formal publick disclosure of his admirable researches. His tenets were fully and freely delivered to his pupils; but he very rarely intruded upon the publick as an author; and his splendid achievements in the philosophy of heat are chiefly developed in his posthumous works. This silence, arising out of an over-cautious modesty which marked all his proceedings, was not favourable to the reputation of Dr. Black. Faulty and incomplete copies of his lectures were circulated among his friends and admirers, which afterwards reached the hands of those who deserve another name, and by whom they were not very honourably employed.

The first researches of Dr. Black, which it will be necessary to attend to, explain the cause of causticity in earths and alkalies. When chalk or limestone, which are mild insoluble tasteless substances, are heated to redness in the open fire, they are converted into quicklime, a body corrosive, soluble in water, and having an acrid flavour. Stahl, Macquer,[1] and Meyer, attributed this change to

[1] Macquer was born at Paris in 1718, and died in 1784. He ranks among the most eminent scientifick Chemists of the early part of the eighteenth century; and though involved in the errours of the Phlogistick school, he has written with much good sense and perspicuity on a variety of chemical subjects. His most celebrated works are, the *Elemens de Chimie Theorique*, Paris, 1749; and *Elemens de Chimie Pratique*, Paris, 1751. He also published

some substance absorbed from the fire,—to an acrid acid,[1] —to phlogiston, and other creatures of the imagination. Dr. Black's mind was turned to this subject in consequence of the discovery of magnesia. This substance made its first appearance as an Arcanum in Italy, in 1707. Valentine showed that it might be obtained from the mother-liquor of nitre, but it was supposed to be lime, until Hoffman, in 1720, pointed out several peculiarities by which it is distinguished from that earth. Hoffman prepared magnesia from bittern, or the saline liquor which remains after the separation of common salt from sea water; to this he added an alkali which precipitated the earth.[2] The

a Chemical Dictionary. The following is all his information respecting the property possessed by quicklime of rendering the alkalies caustick. After describing the process, he observes, "Le but de cette operatiou, est de réunir avec le sel alcali fixe ce que la chaux a de salin et d'âcre."——"On le combine avec la partie la plus âcre, la plus subtile, et la plus saline de la chaux." ——"Nous n'entreprendrons point ici d'expliquer pourquoi le sel alcali, que l'on combine avec la chaux, acquiert une si grande causticité. *Cette question nous paroît une des plus delicates et des plus difficiles à résoudre que nous offre la Chimie.* Elle tient à celle des propriétés alcalines de la chaux, et on ne peut guères espérer de la résoudre, que quand on aura acquis sur la nature de cette substance, beaucoup plus de lumières que nous n'en avons à présent." *Elemens de Chimie Pratique*, pp. 179. 182.

[1] J. F. Meyers, *Chemische versuche zur nähern erkenntniss des ungelöschten kalks; der elastischen und electrischen Materie, des allerreinsten feuerwesens, und der ursprünglichen allgemeinem säure.* Hannover, 1764. In this dissertation, though published subsequently to Black's essay, the causticity of the alkalies and lime is referred to the absorption of a principle which the author calls *Causticum*, or *Acidum pingue.* Between the years 1760, and 1772, a great variety of dissertations were published in Germany upon this question, some in support of Black's doctrine, others in favour of Meyer's hypothetical absurdities. See Gren's *Systematisches Handbuch der Gesammten Chemie.* Halle, 1794. § 437.

[2] *Observ. Phys. Chem.* 1722.

substance which thus exists in bittern, is a compound of magnesia and sulphurick acid. It was first obtained from certain mineral springs in the neighbourhood of Epsom in Surry, and thence called Epsom salt, but was sold at a very high price, in consequence of the small quantities so procured, until the manufacturers in the neighbourhood of Lymington obtained it from sea water; it was then largely exported to the Continent under the name of English salt.

Epsom salt was indeed long confounded with Glauber's salt, and a fraud of the manufacturers here, and in Germany, tended to keep up the confusion; for at that period Glauber's salt was rare in England, and large crystals of Epsom salt were sold under that name; but in Germany, where Epsom salt was not common, Glauber's salt, in small crystals, was vended as English or Epsom salt. Pott of Berlin, and Du Hamel of Paris, were led into a comedy of errours in consequence of mistaking the nature of these bodies.

Dr. Black found that, when magnesia was prepared by precipitating a solution of Epsom salt by a mild alkali, that it effervesced with acids; but that when heated to redness, it lost weight, and then dissolved without effervescence. This fact, which also holds good in respect to lime, induced him to believe that, instead of gaining any

Hoffman was the most celebrated Chemical Physician of the age. He was born at Halle in Saxony, in 1660, and died in 1742. His writings, which are voluminous, are also valuable. In 1749, they were eked out by the Genevese Booksellers into nine folio volumes. The following are his leading Essays in Chemistry:

Dissertationes de Generatione Salium,—De Natura Nitri,—De Cinnabare Antimonii,—De Mirabili Sulphuris Antimonii fixati efficacia,—De Mercurio et Medicamentis Mercurialibus. Observationum Physico-Chemicarum Collectio. Libri iii.

thing in the fire, something was lost by these earths. He, therefore, distilled some magnesia in a retort, but found, that although it lost weight as before, nothing but a relatively small quantity of water was found in the receiver. The experiments of Dr. Hales now rushed into his mind, and it occurred to him, that some gaseous or aeriform body had escaped from the earth, and that this was the cause of its effervescing with acids,—a circumstance previously ascribed to the collision of the acid and earthly particles. He therefore put some magnesia, not calcined, into a bottle, with a bent tube attached to it; and thus, during the action of the acid, obtained a large quantity of an elastick fluid, in a vessel inverted in water; he found, too, that chalk, and common alkali, yielded the same kind of air. The air thus existing in these substances Dr. Black called fixed air; and he proved it to be the cause of mildness in earths and alkalies. If lime be added to a mild alkali, the lime absorbs its fixed air, and renders it caustick,—an effect formerly attributed to the transfer of the fiery particles of the lime.

In the year 1750, Venel observed that Selters, and other sparkling waters, when placed under the receiver of an air-pump, gave out a large quantity of air, and became flat and insipid, and he imitated them by dissolving common soda in water, and adding muriatick acid, which produced an effervescence and gave it briskness.[1] These experiments were a little antecedent to Dr. Black's publication, but they by no means anticipated his discover-

[1] "En 1750, Venel, Professeur de Chimie à Montpellier, reprit le fil de ses expériences en arretant dans l'eau le fluide dégagé des effervescences, et en imitant ainsi. par sa dissolution artificielle, les eaux minérales acidules; *mais il fit encore tous ses efforts pour prouver que c'etoit de l'air.*" Fourcroy, *Histoire*, p. 28.

ies.[1] In 1764 the conclusions of Black were verified, and his views extended, by Dr. Macbride of Dublin, who pointed out several new properties of fixed air, and demonstrated its existence in the atmosphere; for lime exposed to air gradually loses its causticity, and becomes effervescent. The operation of quick-lime as a manure depends upon its power of rendering the inert vegetable matter of the soil soluble, and fit for the nourishment of young plants; an effect which it does not produce when combined with fixed air, or in the state of chalk: hence the lime should be spread quickly over the land, and not left in heaps exposed to the air, by which, as Dr. Macbride has shown, it is rendered mild, and of comparatively small effect.[2]

[1] Dr. Brownrigg of Whitehaven threw out some curious hints respecting fixed air, or, as it is now called, carbonick acid, as early as 1765. In a communication to the Royal Society, printed that year in their *Transactions*, he remarks, "that a more intimate acquaintance with those noxious airs in mines, called *damps*, might lead to the discovery of that subtile principle of mineral waters, known by the name of their *spirit;* that the mephitick exhalations termed the Choak damp, he had found to be a fluid permanently elastick; and, from various experiments he had reason to conclude, that it entered the composition of the waters of Pyrmont, Spa, and others, imparting to them that pungent taste, from which they were denominated *acidulae*, and likewise that volatile principle on which their virtues chiefly depend."

Mr. Lane was the first who ascertained the solubility of iron in water, impregnated with fixed air. *Phil. Trans.* 1769. "By this means," says Sir John Pringle in his discourse on the different kinds of Air, delivered at the anniversary meeting of the Royal Society, November 30, 1773, "the nature of the metallick principle in mineral waters was clearly explained, and the whole analysis of those celebrated fountains, so often attempted by Chemists and others, and still eluding their laboured researches, was thus, in the most simple manner, brought to light."

[2] Macbride's *Experimental Essays*, 1764. The merit of this performance induced the University of Glasgow to bestow the degree of Doctor of Physick on the author.

Such are the principal features of Dr. Black's researches respecting the cause of mildness and causticity in earthy and alkaline substances. They constitute an important body of chemical evidence, and are established upon the satisfactory basis of analytick and synthetick proofs.

I now turn to his more elaborate investigation into the effects of heat; to inquiries so momentous in their influence upon the advancement of experimental philosophy, so replete with difficulties, and so masterly in their execution, as to raise them to the highest efforts of the human mind. I have deemed a rapid glance at the discovery of fixed air sufficient for our present purpose; for occasions will afterwards offer of descanting more largely upon its nature and properties; but the investigation now before us, is that from which the towering and durable greatness of Black's name has been principally derived; and it was begun, continued, and completed, by the labour of his own hands.

In speaking of the graduation of thermometers, it was mentioned, that if snow or ice be brought into a warm atmosphere, and suffered to thaw slowly, the water which runs from it is always at one temperature, that of 32° of Fahrenheit's scale. This and similar cases seem to have occupied the early thoughts of our philosopher; for his biographer informs us, that, in the oldest parcels of his notes, he found queries relating to this subject. How does it happen that, although heat is constantly flowing from surrounding bodies to the ice, its temperature is not increased? Water at 32°. when brought into a room at 60°. goes on increasing in temperature till it attains that of

Dr. Macbride introduced some important improvements into the art of Tanning, and was the first who employed lime water in the preparatory operations of that process. He was born in the county of Antrim in 1726, and died in 1778.

the circumambient air; but the ice, though exposed to exactly similar sources of heat, remains at 32°. Why, when water is cooled several degrees below its freezing point, does its temperature suddenly rise to that point, the instant that it congeals? or why is it, that, when a vessel of water is put upon the fire, a thermometer plunged into it continues to indicate increase of heat until it rises to 212°; and the water then boils, but does not become hotter, although it remains upon the fire, and has all its former opportunities of acquiring heat? Such were the queries which Dr. Black has most happily resolved.

In regard to the liquefaction of ice, he has demonstrated that, when solids pass into the liquid state, the change is always accompanied with the absorption of heat, which is concealed or becomes latent in the liquid, and is not indicated by the thermometer, which instrument, therefore, is no measure of the absolute quantity of heat. A variety of interesting and curious experiments were undertaken with a view to ascertain the quantity of thermometrick heat, which thus becomes latent during the conversion of ice into water. A pound of snow at 32° was mixed with a pound of water at 172°; the snow was melted, and the temperature of the mixture was only 32°; so that here 140° thermometrick heat had disappeared; their effect being, not to raise the temperature of the snow, but to convert it into water. We should say, therefore, from this experiment, that water at 32° is a compound of ice, and 140° of heat as indicated by the thermometer. If water, at the temperature of 32°, be mixed with an equal weight of warm water, suppose at 200°, the resulting temperature will be the mean; $232 \div 2 = 116$; but if we use ice, the temperature will not be the mean, for 140° of heat must be substracted from the warm water, which heat is consumed in liquefying the ice; the result, therefore, will

be the same as if water at 32° and 60° were mixed, giving a mean of only 45°.

These experiments at once demonstrated the cause of many facts respecting the production of heat and cold, which, though long known, remained without any plausible explanation.

When solids become fluids, the production of cold is more or less evident, according to the rapidity of the change. Those saline bodies, for instance, which are very rapidly soluble in water, generate during their solution a considerable intensity of cold, for to become fluid they must absorb heat. When snow and salt are suddenly blended, there is an instant liquefaction, and the temperature of the substances being already low, a degree of cold equal to 0° of Fahrenheit is obtained The production of cold by mixing snow and muriate of lime, a very soluble salt, is—40° Fahrenheit, and sufficient to freeze quicksilver even in a comparatively warm atmosphere. A mixture of 5 parts of sal ammoniack in powder, and 5 parts of nitre with 16 of water, sink the thermometer from 50° to 10°. Equal parts of nitrate of ammonia, and water, produce a more intense cold, and by a clever successive application of these freezing mixtures, the intense degree of cold of—91° Fahrenheit has been artificially exhibited. This is 123° below the freezing of water, and 40° the greatest natural cold hitherto observed, which was at Hudson's Bay, where the spirit thermometer has been seen at 50°.

There are many counter illustrations of this doctrine of latent heat; in which heat is evolved during the conversion of liquids into solids. If oil of vitriol be poured upon magnesia, there is a sudden solidification of the acid by its union with the earth, and a considerable rise of temperature ensues. Water poured upon quicklime produces

a similar phenomenon; and when water at perfect rest is exposed in a covered vessel to an intensely cold atmosphere, its temperature may be reduced to many degrees below its freezing point: A slight agitation causes it suddenly to become ice, and at that instant the temperature rises to 32°. A somewhat similar case is the sudden crystallization of saline solutions, during which their latent heat becomes sensible to the feeling, and is indicated by the thermometer.

In Dr. Black's theory of latent heat, it is assumed that heat is matter; that it is a substance of excessive tenuity, existing in variable proportions in bodies; that when in a free state, it affects our senses, and the thermometer, but that it occasionally enters into union with other substances, or is separated from them, consistent with the usual laws of chemical attraction. Thus, in fluids, it is combined or latent, but when they are converted into solids, it is separated in a free or sensible state. The other view of the question represents heat as the result of a vibrating motion among the particles of bodies; the vibrations being most rapid and extensive in the hottest bodies. In fluids the vibrations are accompanied by a motion of the particles round their own axes; and when solids pass into the fluid state, the vibratory motion or temperature is in part lost, by the communication of the rotatory motion to the particles. Each of these hypotheses has had its able defenders and advocates; the ideas of Newton seem to have been favourable to the latter, and many facts may be adduced in its support. The strongest are the imponderability of heat, and its continuous extrication by friction. That we discover no increase of weight in a heated body may be attributed to the insufficiency of our instruments, but its unlimited production in a variety of

cases, though consonant with the hypothesis of vibration, ill agrees with that of a specifick form of matter.

If a soft iron nail be beaten upon the anvil, it becomes hot and brittle, and it cannot again be rendered malleable till it has been resoftened by exposure to the fire. By those who favour the notion of a matter of heat, this has been called an *experimentum crucis*. The matter of heat, say they, is squeezed out of the nail, as water out of a sponge, but it is reabsorbed in the fire. In this experiment, however, it must be recollected, that the mechanical arrangement of the particles of the iron is considerably altered; it is rendered very brittle; and hence, perhaps, its insusceptibility of becoming again hot, till restored to its former state or texture by the expansive power of fire.

It was not until the publication of the researches which have just been considered, that a variety of curious circumstances concerning congelation were understood. The gradual progress in the freezing of large bodies of water has been shown to depend in some measure upon the remarkable anomaly respecting its maximum of density; but it is also materially connected with the phenomena of latent heat; for water, before it can become ice, must part with a quantity of heat, which if suddenly evolved, would raise the thermometer 140°. It must also be obvious, that the process of thawing suffers a similar retardation, for ice requires for its conversion into water, the absorption of 140°. of sensible heat.

Thus we see that sudden congelation and sudden liquefaction are alike prevented; that the process must be gradual, and consequently productive of none of those evils which would result from a more rapid change.

One of the great advantages of irrigation, or meadow watering, is also explained by a reference to these principles. In an irrigated meadow, the surface of the water

may be frozen; but as water at 40° is heavier than at 32°, the former will be its temperature in contact with the grass; and it is a temperature perfectly congenial to the functions of vegetable life. Sir Humphrey Davy examined the temperature in a water meadow near Hungerford, in Berkshire, by a very delicate thermometer. The temperature of the air, at seven in the morning, was 29°. The water was frozen above the grass; the temperature of the soil at the roots of the grass was 43°. Thus, by the peculiarity in the refrigeration of water, by the defence afforded by the stratum of ice, and by the laws of congelation, the vegetables are not merely protected from the effects of an intensely cold atmosphere, but likewise from the injurious influence of sudden changes of temperature.

Congelation is to surrounding bodies a source of heat, and there is no inconsiderable mitigation of the extreme cold of air wafted over large bodies of water, by the transfer of latent to sensible heat, which must occur before they can freeze.

The theory of freezing mixtures has led to considerable improvements of their applications, and many new and curious discoveries have resulted in pursuing this inquiry. Indeed whatever tends to disclose the laws of nature, cannot ultimately fail of subjecting her more or less to the uses of life, and of manifesting more and more the wisdom of the creator.

Having established the above facts respecting the cause of fluidity, Dr. Black proceeded to the second part of his inquiry, relating to vaporisation, and pursued it with the same abilities and success.[1] Finding the thermometer to

[1] "When we heat a large quantity of a fluid in a vessel, in the ordinary manner, by setting it on a fire, we have an opportunity of observing some other phenomena which are very in-

remain stationary at 212° in boiling water, he conceived the process of ebullition to be in some respects analogous to that of liquefaction, and that the heat which did not raise the temperature of the water, entered into union with it, and became latent in the steam. If this were the case, it should be re-evolved during the condensation of steam; and thus a method was devised of ascertaining its thermometrick quantity. Dr. Black's experiments on this subject were very numerous. I shall allude to such as put

structive. The fluid is gradually heated, and at last attains that temperature which it cannot pass without putting on the form of vapour. In these circumstances, we always observe, that it is thrown into the violent agitation which we call boiling. This agitation continues as long as we throw in more heat, or any of the fluid remains, and its violence is proportional to the celerity with which the heat is supplied.

"Another peculiarity attends this boiling of fluids, which, when first observed, was thought very surprising. However long and violently we boil a fluid, we cannot make it in the least hotter than when it began to boil. The thermometer always points at the same degree, namely, the vaporifick point of that fluid. Hence the vaporifick point of fluids is often called their Boiling point.

"When these facts and appearances were first observed, they seemed surprising, and different opinions were formed with respect to the causes upon which they depend. Some thought that this agitation was occasioned by that part of the heat, which was more than the water was capable of receiving, and which forced its way through, so as to occasion the agitation of boiling; others, again, imagined, that the agitation proceeded from air, which water is known to contain, and which is now expelled by the heat. Neither of these accounts, however, is just or satisfactory; the first is repugnant to all our experience in regard to heat: we have never observed it in the form of an expansive fluid like air: it pervades all bodies, and cannot be confined by any vessel, or any sort of matter; whereas, the elastick matter of boiling water, can be confined by external pressure, as is evident in the experiments made with Papin's digester."

This quotation from Black's *Lectures*, (Vol. I. p. 153,) is inserted to show the state of the argument respecting the phenomena of ebullition previous to his researches.

the phenomenon in the clearest light, and are perfectly unconnected with hypothesis.

He noted the time consumed for raising a certain quantity of water to its boiling point, and then kept up the same heat till the whole was evaporated, and marked the time consumed by the process. It was thus easily computed what the temperature would have been, supposing the rise to have gone on above 212° in the same ratio as below it. The water was originally at 50°; it boiled in four minutes, and in twenty minutes was all evaporated. In four minutes, therefore, it had gained 162° for $50°+162=212$; and in twenty minutes would have gained $162\times5=810°$; which may, therefore, be considered as the equivalent thermometrick expression of the latent heat of the steam. Another good illustration of the absorption of heat in the production of steam, is furnished by heating water under compression. It may then be raised many degrees above its ordinary boiling point; but, on removing the pressure, a portion of steam rushes out, and the remaining water has its temperature lowered to 212°.[1]

Hence we learn, that the conversion of water into vapour is attended with a great loss of heat to the surrounding bodies; and although the perceptible temperature of water and steam are identical, the latter contains heat equivalent to between 800 and 900° of perceptible or thermometrick temperature. When steam is reconverted into water, this large quantity of heat is again given out; and hence a small portion of steam is capable of heating a large body of water to its boiling point. The knowledge of this fact is of great economical importance; and in breweries and other manufactories, where large bodies of water are required to be

[1] See Black's Experiments, which prove the absorption of heat. *Lectures*, Vol. I. p. 157, &c.

boiled, the steam, instead of being suffered, as formerly, to pass off into the air, is conveyed by pipes into other vessels of water, which it heats during its condensation. In the same way, rooms and houses are warmed by the heat evolved during the condensation of steam, in iron or copper tubes which traverse the building, and the method is at once safe and effectual.

It is in consequence of the latent heat of steam, that, in the process of distillation, we are obliged to present so large a surface for condensation ; and it is not difficult, by the help of a still, to calculate the latent heat of steam. If, for instance, one hundred gallons of water at 50° be mixed with one gallon at 212°, the temperature of the water will be raised above 1½°. If, by the common still-tub, one gallon of water be condensed from the state of steam by one hundred gallons of water at 50°, in that case the water will be raised 11°, which is about 9½° more than in the former instance. Hence it appears, that the heat imparted to a hundred gallons of cold water by eight pounds of steam, would, if it could be condensed into one gallon of water, raise it to 950°.

The average of the various experiments, which have been made on this subject, warrants us in placing the latent heat of steam between 900° and 1000°.

These facts demonstrate that the condensation of vapour is always a heating process, and that its formation must equally be attended with the production of cold.

[1] About the year 1774, it was observed by Dr. Cullen, that a thermometer moistened with spirit of wine or ether,

[1] "The Chemistry of Stahl, as it was cultivated in Germany, and France, and other countries of Europe, scarcely aspired beyond the bounds within which it had been circumscribed by its original founder. A few important facts, indeed, were added, but they were either connected with medical preparations, or attracted attention solely as objects of curiosity. The great and tempting field of Philosophical Chemistry lay unexplored, when it was

sinks many degrees during the evaporation of those fluids; with others, the thermometer may be made to fall from 60° to 0°. The cause of this is sufficiently explained by Dr. Black's theory; the ether and spirit readily pass into vapour, which requires a certain quantity of heat for its production; this is taken from the bodies it happens to be in contact with, as from the thermometer or the hand; hence the cold perceived when these fluids are applied to the body, and the advantage which results from their application in cases of burns, and inflammations. These circumstances led Dr. Cullen to accelerate the evaporation of these fluids, by exposing them under the receiver of the air-pump; by placing a flask half full of ether in a tumbler of water, it was found that, during the process of exhaustion, the evaporation was so rapid from the ether in the flask, as to convert the surrounding water into ice.[1]

entered upon with ardour by Dr. Cullen, who first perceived its value, and whose genius and industry, had they not been turned into another channel, would, in all probability, have been crowned with the richest discoveries. But though Dr. Cullen soon abandoned his chemical pursuits for those of medicine, he was fortunate enough to have initiated into the science, a man whose discoveries formed an era in chemistry, and who first struck out a new and brilliant path, which was afterwards fully laid open, and traversed with so much eclat by the British philosophers who followed his career. This fortunate pupil of Dr. Cullen, was Dr. Joseph Black." *Thompson, History of the Royal Society*, p. 468.

Dr. Cullen's fame as a promoter of chemistry has been lost in his greater celebrity as a teacher of medicine. "Chemistry," says his biographer, Dr. Anderson, "which was, before his time, a most disgusting pursuit, was, by him, rendered a study so pleasing, so easy, and so attractive, that it is now pursued by numbers as an agreeable recreation, who, but for the lights that were thrown upon it by Cullen and his pupils, would never have thought of engaging in it at all."

Cullen was born in Lanarkshire, in 1712, and died at Edinburgh in 1790.

[1] Dr. Cullen's paper is published in the *Physical and Literary Essays and Observations*. Edinburgh, 1756. Vol. II. It con-

This part of the philosophy of heat, regarded in its connexion with the phenomena of nature, opens pleasing views of her order and economy. In the constant evaporation from the earth's surface, from rivers, lakes, and the sea, we discern an unfailing cause of equalization of heat ; the vapour thus formed, ascending to colder regions, there becomes a source of increase of temperature, and, re-assuming fluidity, is thrown upon the earth in fertilizing showers, or forming torrents among the mountains, and rivers in the valleys, is returned to the parent ocean, and again becomes active in a similar cycle of changes.

But besides these obvious and complete changes in the state of matter connected with the evolution or absorption of heat, there are others in which similar alteration of temperature is observed, without a positive change of form.

tains the details of many interesting experiments upon the production of cold, and he considers the power of fluids in this respect, as nearly according to the degree of volatitity in each. "If to this," says he, "we join the consideration that the cold is made greater by whatever hastens the evaporation, and particularly that the sinking of the thermometer is greater, as the air in which the experiment is made is warmer, if dry at the same time, I think, we may now conclude, *that the cold produced is the effect of evaporation.*"

A very curious and ingenious method of accelerating the evaporation of water, so as to produce a freezing temperature, has lately been devised by Professor Leslie. If we place a small basin of water under the receiver of the air-pump, its temperature will sink a few degrees during exhaustion. If a large surface of oil of vitriol be at the same time included in the exhausted receiver, the vapour of the water is rapidly absorbed by that fluid, the perfection of the vacuum is thus maintained, the production of vapour is extremely rapid, and the quantity of heat absorbed for its formation so considerable, as to allow of the conversion of the remaining water into ice. Other absorbents, such as dry clay, oatmeal, &c. may be substituted for the acid. The operation of wine and water coolers, and all cases in which diminution of temperature results from evaporation, are admirably explained upon Dr. Black's *Theory of Latent Heat.*

Whenever the density of a body, whether solid, liquid, or aeriform, is varied, there is an equivalent variation in its latent heat. The specific gravity of soft iron is increased by hammering, and heat is evolved during the operation. A piece of Indian rubber, suddenly extended, becomes warm. If water be mixed with oil of vitriol, the density of the water is increased, and there is a very considerable augmentation of temperature. If air be suddenly compressed, it retains its elastick state, but becomes violently heated; on the other hand, if air be quickly rarified, there is an equivalent reduction in its temperature. In these cases, bodies are said to change their capacities for heat; increase of density is attended with a diminution of capacity for heat; and diminution of density with an increased capacity. The phenomena thus presented are such as the doctrine of latent heat would lead us to expect. When a fluid is converted into a solid, there is a copious evolution of heat; when a fluid approximates to a solid state, or where its density is increased, we might expect that heat would also be evolved.[1]

The last train of investigation, in regard to heat, which occupied Dr. Black's thoughts, related to the different quantities of heat contained in different substances of the same temperature, without relation to change of density or state. A reference to an experiment will, perhaps, render this point more intelligible. If, for instance, a given quantity of boiling water, surrounded with ice, in sinking from 212° to 32° melts one pound of ice, and if the same quantity of olive oil, in passing from the same to the same temperature melts only half a pound of ice, we should conclude, that,

[1] The sinking of a thermometer suspended in the receiver of the air pump, during exhaustion, and its subsequent rise upon the readmission of air, are noticed by Dr. Cullen in the paper just quoted.

although the thermometrick temperature of the two fluids is similar, the actual quantity of heat contained in the water, and ascertainable by its effects upon the ice, is twice that contained in the oil. To signify the quantity of heat thus contained in different bodies of the same temperature, the term *specifick heat* has been employed—we thus should state, from the result of the experiment alluded to, the specifick heat of water to be 2, that of the olive oil 1. Irvine, Crawfurd, Wilcke, Lavoisier, and several eminent Experimentalists of the present day, have engaged themselves in researches on this subject, but the inquiry originated with Dr. Black, in the year 1762.

In these limited observations upon the discoveries of Black, I hope to have rendered myself intelligible upon those main points of his investigations, which constitute the foundation of some of the most important and refined doctrines of chemical science. The distinct object of this discourse being to record the march of chemical discovery, and not to unfold the principles of the science, it would be unwise to indulge in more extended incursions upon this fertile ground, or to trace the great trunk of his researches to its extreme ramifications. But a partial glance at the facts disclosed will show even a superficial observer, the obligations we are under to the discoveries of this eminently modest and unassuming Philosopher. Of many of the most intricate phenomena of nature, they furnished new, easy, and luminous explanations ; and to the arts they were of unparalleled benefit ; for, by developing their connexion, not with the shadows merely, but with the depths of science, a new road was opened to their improvement and perfection.

Among the learned lookers-on of this period we discern many who, with independent and liberal minds, loved and patronized science for its own sake, and they were pleased at its rapid progress under the auspicious guidance of

Black. Others, actuated by motives illiberal and interested, countenanced sciences solely upon the selfish principle of gain; the puerile and short-sighted questions of *cui bono* was constantly on their lips; but even they have been silenced by the application of Black's discoveries.[1]

[1] This may he the proper place to show in what way the views of Dr. Black's *Theory of Latent Heat* are connected with the improvements of the steam-engine—a subject upon which I must necessarily be brief, as only in part belonging to the object of this discourse. The Marquis of Worcester is commouly regarded as the inventor of the steam-engine, but his claims are not well authenticated. It is true, that, among the Utopian schemes to be found in his Century of Inventions, there is a dark description of a method of raising water by steam; but we can scarcely see how this was effected, nor are there any data recorded of the success of the contrivance. Be this as it may, he who barely and obscurely hints the possibility of an undertaking cannot be regarded as forestalling him who successfully carries it into execution; and the first person, who, upon decided evideuce, coustructed an eugine for raising water by the alternate force and condensation of steam, was Captain Savary, —who also published an account of his invention in a small tract called the *Miner's Friend.* To enter into a description of this instrument would be irrelative to my present purpose; I therefore pass on to that of Newcomen, who, in 1705, obtained a patent for au improved steam-engine. It consisted of a boiler having a cylinder placed upon it, in which was a solid plunger connected by its rod with a beam and lifting pump. The plunger was elevated by the elastick force of steam admitted from the boiler. The steam-cock being closed, a small stream of cold water was suffered to run into the cylinder, by which the steam was condensed; the pressure of the atmosphere then acting upon the surface of the plunger, forced it to the bottom of the cylinder, whence it was again raised by the readmission of steam, and so on. In 1717, Mr. Heury Beighton became an improver of the steam-engine; he was probably the first who caused the steam-cock to be opened aud shut by the machiuery, for a man was obliged to attend Newcomen's eugiue for this express purpose. A few other improvements were made by different persons, but they did not affect the general action of the engine; the steam was alternately admitted into, and condensed in the main cylinder; and although defects in its power had been noticed, their cause was unknown until 1765,

SECTION IV.

RESEARCHES RELATING TO THE COMPOSITION OF ATMOSPHERICK AIR. —EXPERIMENTS OF RUTHERFORD AND OF PRIESTLEY.

Of the various discoveries, which it is the object of this Dissertation to unfold, none have been more important in their consequences than those relating to the composition

when, happily for the prosperity of the arts and manufactures of this country, the subject engaged the keen ingenuity of Mr. Watt. The model of a Newcomeu's engine fell into his hands to be repaired, and in this he presently observed the immense loss of steam occasioned by its admission into the cylinder just cooled for condensation; indeed, he went so far as to ascertain, by experiment, that half the steam of the boiler was thus lost. For, having constructed a boiler which showed the quantity of steam expended at every stroke of the engine, he found that it many times exceeded that which was sufficient to fill the cylinder. But the circumstance that excited his greatest surprise was, that the injection water gained infinitely more heat than if a quantity of boiling water, equal to that required to form the steam, had been added to it. It was probably in this dilemma that he cousulted Dr. Black—and the explanation of the difficulty will be obvious from the facts detailed in the text. To avail himself, therefore, of the whole power of the steam, it became absolutely necessary to keep up the temperature of the cylinder constantly at the boiling point of water; this he was enabled to attain, by connecting with it another vessel, exhausted of air, and immersed in cold water, into which, when communicated with the cylinder, the steam, being an elastick fluid, instantly rushes and is condensed, and, on closing its connexion with the cylinder, the steam, again admitted there, now operates with full force, and suffers no further condensation. To carry off the water from this second vessel, which he calls the condenser, and to perpetuate the vacuum, Mr. Watt attached to it a pump by which both the air and condensed water are removed. The engine thus altered produced the same power as one of equal dimensions on Newcomen's plan, with rather less than one-third the quantity of steam; hence was a considerable hindrance to the use of the engine

of atmospherick air, a subject which the ancients seem not to have thought upon, since they regarded it as an element, or ultimate principle of matter.[1] In this, as in most other branches of experimental science, the advances of the human mind have been very gradual: Mayow, in 1674, was upon the very brink of that stream of discovery, which, in 1774, carried Priestley into the fastnesses of Pneumatick Chemistry. Hales, by showing the mode of disengaging and collecting gaseous fluids, removed many of the most serious obstacles which encumbered this path

materially diminished, namely, the expense of fuel. But great as was this improvement, it forms a small part of the successful achievements of Mr. Watt in this department of mechanicks; he amended the apparatus for boring the cylinders, and improved every part of the working gear of the engine; and he infinitely extended its applications and utility, by applying the power of steam to produce motion round an axis; but their enumeration would lead me out of the bounds of chemistry. I, therefore, hasten to the invention which may be said to have perfected the steam-engine. Steam had hitherto only been used to force the piston down,—it was returned by a weight attached to the other end of the beam. Mr. Watt, in 1782, constructed an engine in which steam was used to elevate as well as to depress the piston, an alternate vacuum being formed above and below it, by the condenser, as before. An engine upon this plan, executed at Mr. Watt's manufactory at Soho, near Birmingham, was first employed at the Albion Mills in 1788.

An excellent sketch of the history of the steam-engine will be found in the *Edinburgh Review*, Vol. XIII. p. 311.

[1] Thus Lucretius,—

> Aera nunc igitur dicam, quid corpore toto
> Innumerabiliter privas mutatur in horas:
> Semper enim, quodquomque fluit de rebus, id omne
> Aeris in magnum fertur mare, qui nisi contra
> Corpora retribuat rebus, recreetque fluenteis,
> Omnia jam resoluta forent, et in aera vorsa,
> Haud igitur cessat gigni de rebus, et in res
> Recidere assidue, quoniam fluere omnia constat.
>
> *De Rerum Natura*, Lib. V. v. 274.

of research; he was followed by Boerhaave, and afterwards by Black, who, having reached the discovery of fixed air, turned into another road of investigation. Neither Mayow, therefore, nor Hales, nor Boerhaave, nor Black, were very diligent cultivators of Pneumatick Chemistry; they had, indeed, opened the mine, but did not explore it; its treasures were reserved for those whose labours we are now about to recount, and were chiefly borne away by the diligent dexterity of Dr. Joseph Priestley.

If we trust the quotations of Rey already cited, the necessity of air, in the process of combustion, was not only observed, but inquired into by Caesalpinus [1] and Libavius,[2] as far back as the sixteenth and early part of the seventeenth century. Mayow insisted that a part only of the atmosphere was concerned in the phenomena of combustion, and found that air, in which bodies had burned, became unfit for the respiration of animals.[3] As soon as

[1] Born at Arezzo in 1519; died at Rome in 1603. His medical works contain some scattered chemical observations, which, however, are of little importance.

[2] Libavius has sometimes been cited as the most rational chemical inquirer of his age, but of this character I can find no justification in his writings upon chemical subjects; they are either unintelligible, or trifling; he certainly had some merit as a contriver of apparatus, and his furnaces and distillatory vessels appear to have been ingeniously devised.

He died in 1616.

[3] "Nempe animalculum quodvis una cum lucernâ in vitro includatur, ita ut aeri externo aditus praecludatur, quod facilè factu est. Quo facto lucernam istam brevì expirantem videbimus; neque animalculum diu tedae ferali superstes erit. Etenim observatione compertum habeo, animal unâ cum lucernâ in vitro inclusum, haud multò plus, quam dimidium temporis istius, quo aliàs viveret, spiraturum esse." *Tractatus quinque*, cap. vii. He then goes on to show that an animal requires less air than that wanted for the combustion of a candle, and endeavours to prove

it had been ascertained that, in the phenomena of combustion and respiration, a portion of fixed air was generated, the extinction of burning bodies, and the death of animals immersed in air, thus rendered foul, were referred to the presence of that gaseous body, its noxious qualities having been amply proved by Black and others; and this opinion seemed to be sanctioned by the discovery, that air thus tainted by respiration and combustion, might, in some measure, be restored to purity by exposure to the action of lime water, which absorbed the fixed air.

In 1772, Dr. Rutherford, Professor of Botany in the University of Edinburgh, published a thesis on Fixed, or, as it was then called, Mephitick air, from which the following passage is extracted.[1] "By the respiration of animals, healthy air is not merely rendered mephitick, but also suffers another change. For, after the mephitick portion is absorbed by a caustick alcaline lixivium, the remaining portion is not rendered salubrious, and although

that the air in which an animal has been suffocated will not support flame. "Verisimile est autem aerem, qui vitae sustinendae inidoneus est, etiam ad flammam conflandum ineptum esse.—Quoniam ad lucernae deflagrationem majori particularum aerearum copiâ quam ad vitam sustinendam opus sit. Advertendum est autem hic loci, quod etsi flamma vitaque iisdem particulis sustinentur, non tamen propterea putandum est, sanguinis massam reverâ accensum esse. *Tractatus quinque*, L. c. Mayow's observations on the changes produced by the breathing of animals, on the air, are not less acute than those relating to the phenomena of combustion.

[1] "Sed aer salubris et purus, non modo respiratione animali ex parte fit mephiticus, sed et aliam indolis suae mutationem inde patitur. Postquam enim omnis aer mephiticus ex eo, ope lixivii caustici secretus et abductus fuerit, qui tamen restat nullo modo salubrior inde evadit, nam quamvis nullam ex aqua calcis praecipitationem faciet, haud minus quam antea, flammam et vitam extinguit."

it occasions no precipitate in lime water, it nevertheless extinguishes flame, and destroys life."

Thus we have traced the discovery of two gaseous fluids differing from common air: fixed air, discovered by Black, and *azote*, as it has since been called, by Rutherford. The former, a component part of chalk, and of the mild alcalis, the product of the combustion of charcoal, and of the respiration of animals; the latter an ingredient of atmospherick air.

It would be a wearisome and unprofitable occupation to record, even in brief terms, the transactions of a set of cavilling philosophists who started up in this country, and elsewhere, about the present period of our history; their names have sunk into oblivion, and their works were only read while recommended by novelty. Some of them I have reluctantly perused, and have found that they are rather calculated to weary the attention than to satisfy curiosity, or impart information.

I therefore hasten to one of the most remarkable and splendid epochs of chemical science, adorned by discoveries which have been rarely equalled, either in number or importance, and ushered in by a series of sterling facts and memorable investigations. The well known names of Priestley, Scheele, Cavendish, and Lavoisier, now appear upon the stage, and it will be an arduous but gratifying task to follow them through their respective parts. In this recital, a strict adherence to the dates of discoveries would neither be convenient nor useful, and I shall rather therefore deviate a little on this point, than cloud the perspicuity of my narrative, or cramp it by chronological strictness.

Dr. Priestley's character was of so composite an order as to defy brief description or superficial delineation; he was a politician, a divine, a metaphysician, and a philoso-

pher; and in each of these callings he displayed abilities of a peculiar and occasionally exalted description. His copious and important contributions to chemical science are the more surprising, when it is remembered that his philosophical pursuits were merely resorted to as a relaxation in his theological studies; that his mind was under the constant agitation of controversy and dispute; that he was too impatient for deep research, and too hasty for premeditated plans. But, with all these bars against him, he was a thriving wooer of science: he made more of his time than any person of whom I ever read or heard; and possessed the happy and rare talent of passing from study to amusement, and from amusement to study, without occasioning any retrogade movement in the train and connexion of his thoughts.

There is another important feature in Dr. Priestley's character, which may tend to throw some light on his controversy with the French school: He possessed the strictest literary and scientifick honesty; he makes frequent mention of his predecessors and contemporaries, and enumerates the ideas which he borrowed from them, and the experiments they suggested, with more than necessary accuracy and minuteness. His attachment to Chemistry seems to have been formed at Leeds,[1] about the year 1768, and be-

[1] Dr. Priestley was born at Fieldhead, near Leeds, in March, 1733. In 1758, he went to Nantwich in Cheshire, where he established a school, and was, for the first time, enabled to purchase some philosophical instruments, in the use of which he instructed his scholars. In 1761, he removed to Warrington, whence he made regular annual visits to the metropolis, and became acquainted with Mr. Canton, Dr. Franklin, and Dr. Watson, who assisted him in collecting materials for his History of Electricity. In 1767, Dr. Priestley went to Leeds, where his attention was especially directed to the *doctrine of air*, in consequence of residing near a public brewery, where he amused himself by experiments on the fixed air produced by fermentation. "When I

tween that period and the year 1772, he had added several new and highly important facts to the science, which are detailed in a long communication presented to the Royal Society in the spring of that year. It is here that he relates those researches respecting the influence of vegetation upon the atmosphere, which led to entirely new views of the physiology of plants, and which displayed, in a striking light, some of those masterly and beneficent adjustments of nature, by which the different members of the creation are made to minister to each other's wants, and thus preserve that eternal harmony which marks the natural world.

As combustion and respiration were connected with the deterioration of air, it occurred to Dr. Priestley to ascertain how far the growth of vegetables might be productive of similar effects.

" One might have imagined," says he, " that since common air is necessary to vegetable as well as to animal life, both plants and animals would affect it in the same manner; and I own I had that expectation, when I first put a sprig of mint into a glass jar, standing inverted in a vessel of water; but when it had continued growing there for some months,

removed from that house," says he (*Memoirs* of his own life, p. 61,) " I was under the necessity of making the fixed air for myself; and one experiment leading to another, as I have distinctly and faithfully noted in my various publications on the subject, I by degrees contrived a convenient apparatus for the purpose, but of the cheapest kind." Dr. Priestley's first publication on the subject was in 1772, and related to the impregnation of water with fixed air, and the same year, in the month of March, his *Observations on different kinds of Air*, were read before the Royal Society, to which body he continued to communicate his other valuable researches. In 1794, he embarked for America, and took up his residence in Pennsylvania, where he died on the 6th of February 1804.

We have here omitted all allusions to his religious opinions and controversies, referring our readers to his *Memoirs*, and to his life in the *General Biographical Dictionary*.

I found that the air would neither extinguish a candle, nor was it at all inconvenient to a mouse which I put into it."

In experiments of this kind, Dr. Priestley points out the necessity of often withdrawing the dead and dying leaves, lest, by their putrefaction, they should injure the air; he also hints at the noxious powers of some plants, especially the cabbage, of which he kept a leaf in a glass of air for one night only, and in the morning a candle would not burn in it.[1]

Dr. Priestley also extended his experiments to the influence of plants upon air vitiated by animal respiration and by combustion, and found that they in general did not only not contaminate the air, but that they actually restored to purity that which had been rendered impure by flame and breathing; and by showing that this change was effected by groundsel as perfectly as by mint, proved it independent of

[1] At the beginning of the last summer, I confined, in equal portions of atmospherick air, as nearly as possible, equal surfaces of the leaves of spearmint, cabbage, mustard, bean, pea, and the vine. The plants were all thriving, and, during a great part of the day, were exposed to the sun. The bulk of the air, which was confined over water, was not altered either by the mint or vine leaves; the pea and bean leaves caused a slight diminution, but the air, in contact with the cabbage and mustard plant, was lessened by about one fifteenth and one sixteenth of its original bulk, and it extinguished a taper, which the others did not. The duration of each experiment was 48 hours. The average of the thermometer, during the period, was 52°, and of the barometer, 29,5 inches. This is not the place to enter into any explanation of these facts, or to enlarge the account of them; they prove, however, a corroboration of Priestley's assertion, that different vegetables act very differently on the air, and may be useful in adjusting some discordant results of later experimentalists. Some plants are much more gross feeders than others, and the nature of the soil in which they grow may often be, in some degree, judged of by their flavour. Those vegetables which are of a very quick and luxuriant growth, and readily susceptible of the influence of manures, affect the atmosphere more than those whose growth is comparatively slow, and whose foliage is sparing.

the aromatick oil, to which some in their ignorance had been willing to refer it.

That actual vegetation was necessary, and the mere vegetable insufficient, he proved by exposing the pulled leaves of a mint plant to air, which were unproductive of the regeneration effected by the growing sprig.

Dr. Priestley concluded from these experiments, that the noxious air resulting from combustion, and from the breathing of the different animal tribes, formed part of the nourishment of plants; and that the purity of our atmosphere, and its fitness for respiration, were materially dependent upon the functions of growing vegetables.

Mayow in 1674, and Hales in 1724, had observed the production of gaseous matter during the action of nitrick acid upon the metals. I have before alluded to the very rude manner in which Mayow collected it. Hales ascertained its singular property of producing red fumes when mixed with common air. Dr. Priestley resumed these inquiries, and pursued them with clever activity: he found, that, on mixing one hundred parts, by measure, of common air, with one hundred of the air procured by the action of nitrous acid on copper, which he called nitrous gas, red fumes were produced, and there was a diminution of bulk equal to ninety-two parts in the two hundred; so that one hundred and eight parts only remained.

When fixed air was thus mixed with nitrous air, there was no diminution; when air, contaminated by combustion or respiration, was used, the diminution was less than with purer air; and with air taken from different situations, Dr. Priestley thought he obtained rather variable results. Hence the beautiful application of nitrous air to the discovery of the fitness of other species of air, for combustion and respiration.

It was for these discoveries that the Council of the Royal Society honoured Dr. Priestley by the presentation of Sir Godfrey Copley's medal, on the 30th of November, 1773.[1]

[1] "Sir Godfrey Copley originally bequeathed five guineas to be given at each anniversary meeting of the Royal Society, by the determination of the president and council, to the person who had been the author of the best paper of experimental observation for the year past. In process of time, this pecuniary reward, which could never be an important consideration to a man of enlarged and philosophical mind, however narrow his circumstances might be, was changed into the more liberal form of a gold medal, in which form it is become a truly honourable mark of distinctiou, and a just and laudable object of ambition. It was, no doubt, always usual with the Presidents, on the delivery of the medal, to pay some compliment to the gentleman on whom it was bestowed, but the custom of making a set speech on the occasion, and of entering into the history of that part of philosophy to which the experiment related, was first introduced by Mr. Martin Folkes. The discourses, however, which he and his successors delivered, were very short, and were only inserted in the minute books of the Society; none of them had ever been printed before Sir John Pringle was raised to the chair of the Society." Chalmer's *Biographical Dictionary.—Life of Pringle.*

Dr. Franklin, in a letter upon the subject of this discovery to Dr. Priestley, has expressed himself as follows:

"That the vegetable creation should restore the air which is spoiled by the animal part of it, looks like a rational system, and seems to be of a piece with the rest. Thus, fire purifies water all the world over. It purifies it by distillation when it raises it in vapours, and lets it fall in rain; and farther still by filtration, when, keeping it fluid, it suffers that rain to percolate the earth. We knew before that putrid animal substances were converted into sweet vegetables when mixed with the earth and applied as manure; and now, it seems that the same putrid substances, mixed with the air, have a similar effect. The strong thriving state of your mint in putrid air, seems to show that the air is mended by taking something from it, and not by adding to it. I hope this will give some check to the rage of destroying trees that grow near houses, which has accompanied our late improvements in gardening, from an opinion of their being unwholesome. I am certain, from long

Sir John Pringle, who was then President, delivered, on this occasion, an elaborate and elegant discourse upon the different kinds of air, in which, after expatiating upon the discoveries of his predecessors, he points out the especial merits of Priestley's investigations: In allusion to the purification of a tainted atmosphere by the growth of plants, the President has thus expressed himself:

"From these discoveries we are assured, that no vegetable grows in vain; but that, from the oak of the forest to the grass of the field, every individual plant is serviceable to mankind; if not always distinguished by some private virtue, yet making a part of the whole which

observation, that there is nothing unhealthy in the air of woods; for we Americans have every where our country habitations in the midst of woods, and no people on earth enjoy better health, or are more prolifick." *Phil. Trans.* 1772, page 199.

Notwithstanding these researches, which have exposed some very curious facts relative to the chemical physiology of plants, it must be confessed that the causes of the renovation and equality of our atmosphere are yet by no means ascertained; for, although some growing vegetables do, under certain circumstances, purify the air, (by the absorption of carbon and the evolution of oxygen,) yet, when in a state of decay, they invariably add to its contamination, and a general view of the subject would induce us to conclude, that they do as much harm as good, at least, if recent experiments connected with this subject are to be considered as correct.

These are the prominent features of Dr. Priestley's first communication to the Royal Society respecting the different kinds of air, and had he bestowed no other contribution upon chemistry, the facts here detailed would have entitled him to a conspicuous place among the benefactors of the science. The paper is divided into several sections, in which he discusses the nature and properties of fixed air; of the air contaminated by the combustion of candles and of brimstone; of inflammable air; of air infected with animal respiration or putrefaction; of air exposed to the action of mixtures of iron filings and sulphur; of nitrous air; of air in which metals have been calcined, and which has been exposed to the action of white-lead paint; and of air procured by spirit of salt.

cleanses and purifies our atmosphere. In this the fragrant rose and deadly nightshade co-operate ; nor is the herbage nor the woods that flourish in the most remote and unpeopled regions unprofitable to us, nor we to them, considering how constantly the winds convey to them our vitiated air, for our relief and for their nourishment. And if ever these salutary gales rise to storms and hurricanes, let us still trace and revere the ways of a beneficent Being, who not fortuitously, but with design, not in wrath, but in mercy, thus shakes the water and the air together, to bury in the deep those putrid and pestilential effluvia which the vegetables on the face of the earth had been insufficient to consume."

Such were Dr. Priestley's researches, and such the views to which he had been led previous to the year 1773, when he undertook the examination of the air which rises from red lead, and from red precipitate of quicksilver, when those substances are exposed to heat. This, indeed, was one of the topicks upon which Hales had touched before him, but it was passed over with that hasty and superficial carelessness of which his experimental proceeding furnish so many instances, and in which he so often lost the substance by grasping at the shadow.

Dr. Priestley cast his keenest eye upon the prospect now before him, and as the various objects came into view, he followed them up with more than his ordinary diligence and usual sagacity. The track he had entered upon was, indeed, of such abundant promise, as would have insnared the attention and excited the curiosity of one less awake than our author to its interest and novelty. But he, already well initiated in the management of aeriform fluids, proceeded with a rapidity which left his associates far behind, and carried him, in proud and undisputed precedence, to the goal of discovery.

The 1st of August 1774 is a *red-letter day* in the annals of Chemical Philosophy, for it was then that Dr. Priestley discovered dephlogisticated air. Some, sporting in the sunshine of rhetorick, have called this the birth-day of Pneumatick Chemistry; but it was even a more marked and memorable period; it was then (to pursue the metaphor) that this branch of the science, having eked out a sickly and infirm infancy in the ill-managed nursery of the early Chemists, began to display symptoms of an improving constitution, and to exhibit the most hopeful and unexpected marks of future importance.

Dr. Priestley's original opinion, that all kinds of factitious air were noxious, seems first to have been shaken by observing that a candle would burn in air procured by distilling nitre in a gun barrel; but the first experiment, which led to a very satisfactory result, was conducted as follows. A glass jar was filled with quicksilver, and inverted in a basin of the same; some *red precipitate of quicksilver* was then introduced, and floated upon the quicksilver in the jar; heat was applied to it in this situation by a burning lens, and "I presently found that air was expelled from it very readily. Having got about three or four times as much as the bulk of my materials, I admitted water into it, and found that it was not imbibed by it. But what surprised me more than I can well express, was, that a candle burned in this air with a remarkable vigorous flame, very much like that enlarged flame with which a candle burns in nitrous air exposed to iron or liver of sulphur; but, as I had got nothing like this remarkable appearance from any kind of air besides this peculiar modification of nitrous air, and I knew no nitrous acid was used in the preparation of *mercurius*

calcinatus, I was utterly at a loss how to account for it."[1]

He afterwards obtained the same kind of air by exposing red lead and several other substances to heat, and made a number of well-devised experiments upon its properties.

Those who, for the first time, witness the effect of this air upon burning bodies, will best picture to themselves the emotion and surprise of its discoverer, when he plunged a burning taper into it. The splendour of the flame was magnificently increased, the consumption of the wax was extremely rapid, and the heat evolved much more considerable than in common air. He found, in short, that, in all cases of combustion, the process was infinitely more rapid and perfect in this kind of air, than in the ordinary atmosphere;[2] and he was thence induced to apply the term *dephlogisticated* to the gas he had thus obtained. He regarded it as air deprived of phlogiston, and thus accounted for its eager attraction for that principle which, during combustion, bodies were imagined to throw off.

[1] *Experiments and Observations on Different Kinds of Air*, &c. Vol. II. p. 107. *Birmingham*, 1790.

[2] The following paragraph, with which Dr. Priestley prefaces his account of the discovery of dephlogisticated air, presents a picture of his mind in regard to the origin of his own researches.

"The contents of this section will furnish a very striking illustration of the truth of a remark which I have more than once made in my philosophical writings, and which can hardly be too often repeated, as it tends greatly to encourage philosophical investigations; viz. that more is owiug to what we call *chance*, that is, philosophically speaking, to the observation of *events arising from unknown causes*, than to any proper design or preconceived *theory* in this business. This does not appear in the works of those who write *synthetically* upon these subjects, but would, I doubt not, appear very strikingly in those who are the most celebrated for their philosophical acumen, did they write *analytically* and ingenuously." (*Exp. and Obs.* Vol. II. p. 103.)

On the contrary, he accounted for the extinction of flame by the air discovered by Rutherford, and since termed azote [1] or nitrogen,[2] upon the idea that that aeriform fluid was charged or saturated with phlogiston, and he therefore called it phlogisticated air.[3]

In enumerating the higher merits of Dr. Priestley as a discoverer, we must not forget the minor advantages which his ingenuity bestowed upon experimental Chemistry.—He supplied the Laboratory with many new and useful articles of apparatus, and the improved methods of managing, collecting, and examining gaseous fluids, were chiefly the results of his experience. He was the first who, with any chance of accuracy, endeavoured to ascertain the relative or specifick gravities of the different kinds of air then known; he observed that dephlogisticated air was rather heavier, and phlogisticated air somewhat lighter, than that of the atmosphere; nitrous air he conceived to be nearly of the same specifick gravity. His experiments were made by the help of a delicate balance and exhausted flask.

The influence upon the respiration of animals of a species of air marked by the eminent perfection with which it supports combustion, did not escape Dr. Priestley's notice. On applying to it his test of nitrous air, he found the absorption produced on mixture greater than with atmospherick air; whence he conjectured its superiour fitness for the support of life; he introduced mice into it, and found that they lived longer than in an equal bulk of atmospherick air; he then had the curiosity to taste the

[1] From α and ζωη, "destructive of life."

[2] *i. e.* Producer of nitrick acid.

[3] The application of dephlogisticated air to obtain intense degrees of heat, and its probable uses in medicine, were subjects which did not altogether escape Dr. Priestley's attention, and he has alluded to them in the section of the work already quoted, relating to its "Properties and uses."

gas himself, and after two or three respirations, he felt, or fancied he felt, a peculiar sensation of lightness and ease of the chest. "Who can tell," says he, "but that in time this pure air may become a fashionable article in luxury.—Hitherto only two mice and myself have had the privilege of breathing it." To this he foolishly adds, that "the air which nature has provided for us is as good as we deserve."

We have not yet exhausted Dr. Priestley's discoveries, but have seen enough to establish his claims to the title of a great benefactor to chemical science. If we compare him with his predecessor Black, he falls short in depth of judgment, but in quickness of conception, and industry of pursuit, he excels even such a standard of comparison. The one climbed the hill of discovery with slow and cautious steps, and calmly enjoyed the surrounding views; the other made a more rapid ascent, but was giddy when he reached the summit; hence those distortions and misconceptions, those erroneous notions and hasty conclusions which he who turns over the philosophical writings of Dr. Priestley cannot fail to discern.

Upon the other productions of his pen, metaphysical, political, and moral, it is neither my province nor inclination to dwell; they abound in the defects, but are deficient in the merits, of his tracts upon chemical subjects.*

From the commencement to the termination of his busy career, Dr. Priestley was a staunch supporter of the unintelligible system of phlogiston; he adopted it in all its original incoherence and absurdity; and the last of his scientifick publications was a tract in its defence, in which are adduced a variety of objections to the revived hypotheses

[* It is much to be regretted, that the ingenious author should hazard this sweeping censure—a censure altogether out of place, and, as many will think, not less unfounded than impertinent.]

of Rey and Mayow, and Hooke, which having long lain dormant, were at this time erupted into the chemical world under the specious title of the French theory.[1]

It will not be denied that the leading facts just detailed threw considerable light upon the nature and properties of atmospherick air; but those who have entitled Dr. Priestley the discoverer of its composition, have somewhat overstepped the bounds of correctness.

He seems, indeed, to have possessed no just notions of the difference between phlogisticated and dephlogisticated air; and, instead of regarding them as distinct chemi-

[1] The tract alluded to in the text was published by Dr. Priestley after his retirement to America in 1800. It is entitled, *The Doctrine of Phlogiston established, and that of the Composition of Water refuted.* It contains a variety of miscellaneous observations on the phlogistick and antiphlogistick theories, but it would be useless to follow the author into his unsubstantial speculations on these subjects. He has, however, thrown out some important considerations relating to his claims of originality as the discoverer of dephlogisticated air. The following paragraph appears of sufficient importance to be transcribed. "Now that I am on the subject of the *right to discoveries*, I will, as the Spaniards say, leave no ink of this kind in my inkhorn; hoping it will be the last time that I shall have any occasion to trouble the publick about it." M. Lavoisier says (*Elements of Chemistry, English translation*, p. 36,) "this species of air (meaning dephlogisticated) was discovered almost at the same time by Mr. Priestley, Mr. Scheele, and myself." The case was this:—Having made the discovery some time before I was in Paris in 1774, I mentioned it at the table of M. Lavoisier, when most of the philosophical people in the city were present; saying, that it was a kind of air in which a candle burned much better than in common air, but I had not then given it any name. At this all the company, and M. and Madame Lavoisier as much as any, expressed great surprise; I told them I had gotten it from *precipitate per se*, and also from *red lead*. Speaking French very imperfectly, and being little acquainted with the terms of chemistry, I said *plomb rouge*, which was not understood, till M. Macquer said, I must mean *minium*. Mr. Scheele's discovery was certain independent of mine, though I believe not made quite so early." P. 88.

cal principles, adopted the notion of one elementary substance, charged, in the one instance, with the imaginary essence of inflammability, and free from it in the other. In these inquiries, he frequently verges upon more correct and refined views, but has no sooner entered the right path, than phlogiston, like an *ignis fatuus*, dances before his eyes, and leads him into the marshy mazes of errour.

In the preceding investigations, Priestley followed those methods of collecting aeriform fluids over water, which Hales and others had employed before him: he now ascertained that there were some gases absorbed by or soluble in water. Mr. Cavendish, one of the most eminent Philosophers of that day, had announced this circumstance, and was puzzled by it; but Dr. Priestley, with his usual and dexterous ingenuity, overcame the difficulty, by employing quicksilver instead of water, over which fluid metal he preserved and examined several kinds of air, which are instantly deprived of their elastick state by the contact of water.

The first permanently elastick fluid of this description which he examined, was the muriatick acid; he obtained it by heating copper in the fluid acid, or common spirit of salt, and called it marine acid air.

He immediately ascertained its absorption by water, and its powerful acidity; he found it incapable of supporting flame, and extremely destructive of animal life. He examined the action of a variety of substances upon this gas, and ascertained the remarkable rapidity with which it is absorbed by charcoal, and several vegetable and animal substances. Some unsuccessful attempts were made to ascertain the specifick gravity of this gas, from which Priestley correctly concluded, however, that it was a little heavier than air.

This success attending these experiments, and the readiness with which he procured and retained the gaseous muriatick

acid, led him to extend his trials to other acids, when he found that, by acting upon vitriolick acid by inflammable substances, he could procure from it a permanently elastick fluid, to which he gave the name of vitriolick acid air; he found that, like the marine acid air, it was rapidly absorbed by water, and must be collected and preserved over quicksilver; that it was nearly twice as heavy as atmospherick air; that it extinguished flame, and was instantly fatal to animal life; that it reddened vegetable blues, and destroyed most colours. This air is, in fact, produced by burning sulphur in the atmosphere, and straw, wool, and other materials, are frequently bleached by exposing them to its fumes.[1]

[1] Having elsewhere praised Dr. Priestley's candour, I insert the following extract from his history of the discovery of *Vitriolick Acid Air*, to show the exactness with which he acknowledges the hints and assistance of others:

"My first scheme was to endeavour to get the vitriolick acid in the form of air, thinking that it would probably be easy to confine it by quicksilver, for, as to the nitrous acid, its affinity with quicksilver is so great that I despaired of being able to confine it to any purpose. I, therefore, wrote to my friend Mr. Lane to procure me a quantity of volatile vitriolick acid," &c. "Seeing Mr. Lane the winter following, he told me, that if I would only heat any oily or greasy matter with oil of vitriol, I should certainly make it the very thing I wanted, viz. the volatile or sulphureous vitriolick acid; and, accordingly, I meant to have proceeded upon this hint, but was prevented from pursuing it by a variety of engagements.

"Some time after this I was in company with Lord Shelburne, at the seat of Mons. Trudaine, at Montigny, in France; where, with that generous and liberal spirit by which that nobleman is distinguished, he has a complete apparatus of philosophical instruments, with every other convenience and assistance for pursuing such philosophical inquiries as any of his numerous guests shall choose to entertain themselves with. In this agreeable retreat I met with that eminent philosopher and chemist, Mons. Montigni, Member of the Royal Academy of Sciences; and conversing with him upon this subject, he pro-

Having thus obtained permanent aeriform fluids, having acid qualities, it occurred to Dr. Priestley, that the volatile alcali, the substance which gives pungency to salvolatile, spirit of hartshorn, and similar compounds, might be also procured in a pure and isolated gaseous form; and, after several unsuccessful trials, he succeeded, by heating a mixture of quicklime and sal ammoniack, when a great quantity of air escaped, permanent over quicksilver, but, like the acid gases, rapidly absorbed by water.

The odour of this gas was pungent in the extreme, and it possessed the property of salvolatile, smelling salts, and similar substances, of turning vegetable blues to green. After several experiments, in which the absorbing powers of different substances in regard to this air, were tried, Dr. Priestley became impatient to discover the effect of mixing it with the acid airs just described,—he imagined that he should form a neutral air. On putting this notion, however, to the proof of experiment, he was surprised to observe that when marine acid air, and the volatile alcaline air, were mixed in due proportions, they were wholly condensed into a solid. And with sulphureous air a very similar result was afforded.

Dr. Priestley concluded that alcaline air was considerably lighter than acid air, because, on mixing them over mercury, he observed the former to float above the latter;

posed our trying to convert oil of vitriol into vapour, by boiling it on a pan of charcoal in a cracked phial. This scheme not answering our purpose, he next proposed heating it together with oil of turpentine. Accordingly, we went to work upon it, and soon produced some kind of air confined with quicksilver; but our recipient being overturned by the suddenness of the production of the air, we were not able to catch any more than the first produce, which was little else than the common air which had lodged on the surface of the liquor, and which appeared to be a little phlogisticated, by its not being much affected by a mixture of nitrous air."

on putting a lighted candle into alcaline air the flame was enlarged, and a portion of the air appeared to burn with flame.

We have now considered the principal discoveries of Dr. Priestley, upon which his title to originality rests, and it must be allowed that they are not less important than numerous. If we even consider them merely as insulated facts, they are of a very superiour character, and tended greatly to enlarge our knowledge of the chemical elements of matter ; but the new views of many natural and artificial phenomena, which they exposed, and which before were buried in deep obscurity, confer upon them a more exalted aspect, and have obtained for them the deserved meed of universal admiration. In perusing Dr. Priestley's tracts, we find the thread of the narrative occasionally knotted with conceit, and weakened by garrulity; but these blemishes are compensated by prevailing candour and perspicuity of style : he had greatly extended the boundaries of science, and was awake to the importance of his conquests; but resisted that febrile thirst of innovation and reform, which was endemick among contemporary Chemists.

"At present," says he, in the Preface to his third volume of *Experiments and Observations*, relating to various branches of Natural Philosophy, "At present all our *systems* are in a remarkable manner unhinged by the discovery of a multiplicity of *facts*, to which it appears difficult or impossible to adjust them : We need not, however, give ourselves much concern on this account. For when a sufficient number of new facts shall be discovered, towards which even imperfect hypotheses will contribute, a more general theory will soon present itself, and perhaps to the most incurious and least sagacious eye. Thus, when able navigators have, with great labour and judgment, steered towards an undiscovered country, a common sailor, placed at

the mast head, may happen to get the first sight of land. Let us not, however, contend about merit, but let us all be intent on forwarding the common enterprise, and equally enjoy any progress we may make towards succeeding in it, and, above all, let us acknowledge the guidance of that great Being, who has put a spirit in man, and whose inspiration giveth him understanding." With this quotation, sufficiently characteristick of his general style, I shall take leave of Dr. Priestley, and introduce another hero of chemical history, his contemporary and great rival, Scheele.

SECTION V.

DISCOVERIES OF SCHEELE AND CAVENDISH.

Among those whose names became eminent in the history of chemical science during the first half of the eighteenth century, Margraaf and Bergman are entitled to particular mention. The former was a pupil of the once celebrated Neumann,[1] a man whose works are now not much thought

[1] Casper Neumann was born at Zullichau in Prussia, in 1682, and in 1705 we find him enjoying the patronage of the King of Prussia, by whom he was sent to complete his studies at the University of Halle. In 1711, he became a pupil of Boerhaave, and shortly after visited England, whence he accompanied George I. to Hanover, in 1716. In 1723 he became Professor of Practical Chemistry in the Royal College of Bertin, where he died in 1737. His works consist chiefly in dissertations on various subjects of chemical inquiry, published in the *Transactions of the Royal Society*, and in the *Miscellanea Berolinensia.* His Lectures were not printed till after his death, and proved a valuable magazine of chemical knowledge. "The author," says Dr. Lewis, who edited his works, "biassed by no theory, and attached to no opinions has inquired by experiment into the proportions and uses of the most considerable natural and artificial productions, and the preparations of the principal commodities which depend

of, but who did considerable service to the Chemistry of his day, and was evidently possessed of great diligence and some capacity. In 1733, Margraaf[1] pursued chemistry under Juncker at Halle, and, having returned to Berlin in 1738, we find several of his contributions in the *Transactions of the Scientifick Society* of that capital. Subsequent to that period, his works were collected and published at Paris in 1762. They contain a great body of information, at that time novel and important, but they are chiefly entitled to notice as furnishing specimens of the art of analysis, which was afterwards carried to greater perfection by Bergman,[2] who, indeed, may be considered as the first who pointed out the true objects of that branch of the science, and who aimed at conferring upon it the statical accuracy which has since rendered it so important and useful.

But Bergman was something more than a diligent experimentalist and acute reasoner ; he was also an active patron of science, and had the merit of rescuing Scheele from his obscure situation, and of discerning that talent and genius in the bud, which was afterwards so vigorously fruitful.

If we compare Scheele with our own countrymen, we discern him possessed of the accuracy and cool judgment of Black, conjoined with the inquisitive and busy activity of Priestley, and his success in the pursuit of science was

on chemistry; and seems to have candidly, and without reserve, communicated all he discovered."

[1] Born at Berlin in 1709, where he died in 1782.

[2] Torbern Bergman was born in Sweden in 1735, and died in 1784. His principal chemical papers are contained in the *Opuscula*, published at Upsal in 1779. They contain much to admire, not merely as being rich in facts and discoveries, but also on account of the general view which he takes of the mode of prosecuting philosophical inquiry, and which is so ably set forth in the preliminary essay, *De Indagando Vero*. The *Opuscula* was translated into English by Dr. Edmund Cullen in 1788.

such as might be expected to flow from this happy and rare union of opposite talents. In the number of his discoveries, their weight, and novelty, he has indeed very few equals; nor has their splendour been tarnished by time, or dimmed by the brilliant light of modern investigation.

Scheele is among the fortunate few, who, starting from an obscure original, have attained the zenith of scientifick eminence. He was born in 1742 at Stralsund, where his father was a tradesman. His youthful days were passed in the house of an Apothecary at Gottenburgh, where, by singular perseverance, and that kind of industry which is prompted by strong natural inclination, he acquired a valuable stock of chemical information. In 1773, having removed to Upsal, accident brought him acquainted with Bergman, who became his friend and patron, and to whose honour be it told, that when Scheele's reputation afterwards rose to such a height as threatened to eclipse his own, instead of listening to the voice of jealousy, which, on such occasions, is too common a frailty, he became more zealous in behalf of his rival, and more indefatigable in the service of his friend. Scheele afterwards removed to Koping, in the neighbourhood of Stockholm, where he died in 1786.

No adventitious aid, however, can be said to have contributed to Scheele's greatness. On the contrary, obstacles were opposed to his progress which would have damped the ardour, and checked the flight, of less aspiring and persevering minds; and much of his useful life was spent, "not in the soft obscurities of retirement, or under the shelter of academick bowers, but amid inconvenience and distraction, in sickness and in sorrow."

Scheele's first publication, which appeared in the *Stockholm Memoirs*[1] for the year 1771, relates to the analysis of fluor spar. The peculiarities of this substance were first noticed in 1768 by Margraaf, but the discovery of the principle upon which they depend was reserved for the superiour sagacity of Scheele, who demonstrated in it the existence of lime, and acid till then unknown, which he called fluorick acid. Scheele had applied acid of vitriol with great success to the analysis of a variety of substances, and on exposing powdered fluor spar to its action in a glass retort, he obtained the new body in question. The fluorick is one of the few acids which rapidly corrode glass; it dissolves silicious earth, a component part of glass; and forms with it in an aeriform compound, permanent until it touches water, when part of the silicious earth is deposited. Scheele, not aware of this fact, at first conceived that silicious earth was a compound of fluorick acid and water, for, on evolving the gas in a glass retort, and allowing it to pass into water, every bubble was coated with a film of flint;-but he afterwards learned, that it was derived from the retort, which is soon eaten into holes. It is this property of fluorick acid which has led to its employment for the purpose of etching upon glass.

Scheele was next occupied in a series of researches on manganese, a mineral substance abundant in many parts of the world, but of which the nature was unknown until the appearance of his *Dissertation* upon it in 1774. This tract is full of important facts, and glitters with brilliant discoveries. We are here first informed that manganese is a metallick calx; that in its crude state it often contains a peculiar earth, to which the name *barytes* has since been

[1] Scheele's *Essays* have been collected and translated into English by Dr. Thomas Beddoes. London, 1786.

applied; that the volatile alcali contains nitrogen as one of its essential component parts. But the most remarkable novelty announced in this Essay, is the discovery of a peculiar gaseous fluid of a yellow colour, which Scheele considered as the basis of the muriatick acid; conceiving the addition of phlogiston requisite to the restoration of its acid properties. This *dephlogisticated marine acid*, as its discoverer termed it, was examined by him with some precision, and many of its leading characters ascertained, especially its power of destroying colour, which has since rendered it of so much importance to the bleacher. It has since been termed *oxymuriatick acid*, and more recently, *chlorine*. Besides the valuable facts to which I have now alluded, Scheele's *Essay on Manganese* contains others of considerable interest and importance. There can be little doubt that he discovered azote about the same time as Dr. Rutherford. He obtained it by exposing compounds of sulphur, and the alcalies and earths, to confined portions of atmospherick air. He found a part was absorbed, and that the remainder, though not fixed air, was still incapable of supporting combustion. He went a step farther, and demonstrated the existence of azote in the volatile alcali or ammonia, from which he obtained it by the action of certain compounds of manganese.

For our knowledge of the method of obtaining tartarick and citrick acids in their pure state from tartar and lemon juice, we are also indebted to Scheele, and for a variety of curious and interesting documents relating to some of the metallick acids, and their combinations. A compound of one of the acids of arsenick and copper was particularly described by him, and recommended as a green pigment; he prepared it by adding to a solution of blue vitriol, an alcaline solution of white arsenick.

His chemical tracts on the nature and properties of milk, his observations on ether, on the preservation of vinegar, on Prussian blue, and on the nature of the acid matter in various fruits, are all entiled to the highest praise. A just notion of their excellence may be formed by comparing them with the essays of the ablest Chemists of the present day: in regard to experimental accuracy and just conclusion, they generally stand this severe test; no small merit, when his humble means and deficient education are thrown into the balance against him.

But, of the various works of Scheele, that which is most decidedly characteristick of an inventive and original genius, is his *Chemical Observations and Experiments on Air and Fire*. Every page of this treatise has its merits, and they are distinct and peculiar; sometimes we are struck with the sagacity of his inductions, at others, with the appropriateness of his experiments. The facts are detailed in intelligible, clear, and distinct arrangement; the theoretical speculations are adduced with that caution and modesty which ensures attention, and often commands acquiescence. Nor is this essay deficient in original discoveries of the highest class. He obtained oxygen from manganese without any knowledge of Priestley's prior claims; he calls it *empyreal air*, and has detailed its properties and several modes of procuring it, with becoming accuracy and minuteness. Upon the composition of the atmosphere, and of metallick calces, he dwells at considerable length, and relates several remarkable facts concerning the chemical powers of the prismatick rays, and the radiation of terrestrial heat.[1]

[1] In this admirable Dissertation, Scheele points out the difference between the heat which radiates from a heated surface, and that which is diffused by currents of hot air. He also shows, that terrestrial radiant heat does not pass through glass,

From one who wrote in that twilight period, when chemical philosophy was emerging from errour and absurdity, we are not to expect the logical accuracy required at the present day. Scheele is sometimes hasty, and occasionally unintelligible; but seldom careless, and never ridiculous. Different men will form different estimates of Scheele's talents, and although I cannot agree with a contemporary biographer who designates him "as the brightest ornament of human nature, and the most extraordinary man that ever existed;" it will, I think, be generally admitted, that he was an acute and industrious philosopher, and an upright honourable man.

Of the Chemical Philosophers that adorned the last age, the Honourable Henry Cavendish[1] stands foremost in the first rank.

While Priestley and Scheele were extending the boundaries of knowledge, and pursuing that brilliant career of which I have just presented an outline, Cavendish was not less successfully employed in another train of investigation.

Van Helmont, Mayow, and Hales, had, by a series of crude and imperfect experiments, demonstrated the existence of inflammable aeriform fluids; but the nature of the peculiar principle to which they owe their inflammability had been but very imperfectly ascertained, till Cavendish turned his mind to the subject, and published upon it in the *Philosophical Transactions for* 1776. The paper I allude to consists of three tracts, relating to inflammable, fixed, and nitrous air. The first is chiefly entitled to

while that of the sun does; that polished glass and metal reflect both heat and light, but that both are absorbed by a surface covered with lamp black; and that the direction of radiant heat is not diverted by a current of air.

[1] Born in London on the 10th of October 1731.

attention from its originality and importance; in the others he had been anticipated by Mayow and Black, or excelled by Priestley, Scheele, and others of his contemporaries.

By acting with dilute acids upon iron, zinc, and tin, Mr Cavendish obtained an inflammable elastick fluid. He found that it was afforded in the largest quantity by zinc, and that iron yielded more than tin; and he particularly mentions, that the state of dilution, and quantity of the acid, provided it was sufficient to effect the solution of the metal, did not affect the quantity or quality of the air. He discovered in the gas thus obtained several characters, which at once distinguished it from the other varieties of the air then known. It was not absorbable by water, it extinguished flame, and was fatal to animal life; but, when a candle was presented to it, it inflamed; and, when pure, burned with a blue lambent light. It was found to be the lightest known form of ponderable matter. Mr Cavendish considered it as about eleven times lighter than atmospherick air; but subsequent experiments have shown that, when it is rendered perfectly dry, and collected in a state of purity, it is about thirteen times lighter than atmospherick air. Compared with oxygen or dephlogisticated air, its relative weight is as 1 to 15.[1]

[1] This circumstance has led to its application for filling air balloons, which formerly were made to ascend by distension with rarefied air—a large quantity of fuel became thus necessary, which was greatly inconvenient on account of its weight; and the flame required for the rarefaction of the air inclosed in the balloon, was dangerous in the extreme—by confining inflammable air in a silk bag, of sufficient dimensions, its small specifick gravity enables it to float in our atmosphere. The first ascent, with a balloon filled with hydrogen, was performed in France by M. Charles, on the 1st of December 1783—he rose to the enormous height of 10,500 feet above the earth's surface. There is a passage in Dewynt's *Sermons*, published in

He next proceeded to examine the results afforded by burning mixtures of inflammable and common air; and found that, in the proportion of one part of the former to about three of the latter, the mixture exploded on the contact of flame; and that, when the vessel in which this inflammation was performed was previously dry, it always became moist after the explosion.

This circumstance was noticed by Macquer in 1766, and shortly after by Priestley, but that *water* was the result of the combustion, seems first to have occurred to Mr. Watt, who suggested the idea to Dr. Priestley in 1783.

In January 1784, Mr. Cavendish presented a paper to the Royal Society, entitled *Experiments on Air*, in which, after some preliminary remarks, he adverts to Mr. Warltire's experiments, related by Dr. Priestley, upon the formation of dew during the combustion of inflammable with common air, which by that gentleman was referred to the deposition of the air's moisture during its phlogistication; for by the Chemists of that period, inflammable air seems to have been considered identical with phlogiston.

The method in which Mr. Cavendish pursued this inquiry was not less new than satisfactory, and the body of evidence adduced, so conclusive as to convince the most sceptical mind of the accuracy of his deductions.

To ascertain the nature of the products of the combustion of inflammable air, he had recourse to two plans: he burned it slowly and rapidly,—in the one instance, a stream of the air issuing from a small tube, was inflamed in contact with the atmosphere, or oxygen; in the other, the two gases were mixed, and suddenly detonated; and he

1658, from which it has been concluded, that balloons were known at that early period.

found that, proper precautions having been taken to exclude extraneous bodies, the result was perfectly pure water; "it had no taste nor smell, and left no sensible sediment when evaporated to dryness, neither did it yield any pungent smell during the evaporation; in short, it seemed pure water."[1] His grand discovery of the composition of water necessarily led to a variety of others, scarcely inferiour in importance, and it tended to the elucidation of a variety of intricate phenomena in nature and art, in which that universal fluid is concerned. It was verified and established by the analytick and synthetick researches of many modern Chemists, and it became a great organ in subverting the phlogistick doctrine.

In the synthetick experiments proving the composition of water, originally devised and executed by Cavendish, he frequently observed the production of acid matter; the water formed was sour to the taste, and reddened vegetable blues; and he ascertained that these effects arose from the presence of a portion of nitrous acid. Whence this was derived remained to be proved,—whether the elements which, in one proportion, formed water, produced, in another proportion, the nitrick acid, or whether it resulted from other causes. In a paper read before the Royal Society, in June 1785, Mr. Cavendish sets this curious and interesting question at rest, and developes the source of the acid which appeared in his former investigations. It arose from the presence of a portion of azote, which, when made to unite with oxygen, produced nitrick acid. The atmosphere has already been shown to consist of azote and oxygen,—these gases are there merely mechanically mix-

[1] *Philos. Trans.* 1784. p. 129. Inflammable air has since received the name *hydrogen*, i. e. generator of water.

ed; when they are made to combine in the presence of water, nitrick acid results.

This curious fact was proved by several experiments. That which is most simple, and most satisfactory, consisted in confining a small portion of atmospherick air in a bent tube over quicksilver, and passing the electrick spark for some hours through the mixture. A diminution took place in its bulk, the mercury was corroded, and, on introducing a solution of potash, it became saturated, and yielded nitre on evaporation, a salt composed of potash and nitrick acid.

These are the principal discoveries with which Cavendish enriched the science of Chemistry; they relate to the properties of hydrogen or inflammable air, to the composition of water, and to the constitution of the nitrick acid. They are detailed in three communications to the Royal Society; the first stands in the *Philosophical Transactions* for 1766; the other two in the volumes for 1784 and 1785.

Those who have heard Mr. Cavendish designated the Newton of Chemistry, and have only hastily perused his tracts, or witnessed imperfect illustrations of his researches, may perhaps regard him less worthy that honourable and high distinction than his contemporaries Priestley and Scheele; but a more careful examination of his writings, and a comparison of his reasoning and methods of research with those of even his most eminent fellow-labourers in science, will unanswerably support his claims, and display such peculiar and varied excellence, as must justify the highest encomiums and most elaborate eulogies which have been bestowed on his exalted name. In his philosophical proceedings, the severest scrutineer is challenged to detect a single false step, for every conclusion he has formed, every theory that he has advanced, even every sentence

he has written, will bear microscopick examination. Aware that there was no royal road to philosophick truth, he relied solely upon the light of experiment, in the path of induction, and from this he never deviates. If he excelled not his contemporaries in the number of his discoveries, he certainly equalled them in their importance, and went far before them in statical accuracy and mathematical precision: but as a Philosopher he scarcely admits of comparison; in him most of the defects of his contemporaries were absent, and their talents concentrated; he was "himself alone." In Cavendish science may boast of a follower not less disinterested than successful: his affluence was princely, and his family noble; it was therefore not the desire of distinction in society, nor the more imperious call of necessity, but the thirst for knowledge, and love of truth, that summoned him to her banners.

Mr. Cavendish did not lisp in the language of science; it was, indeed, late before he appeared as a candidate for philosophick fame. His first paper was published in the *Transactions of the Royal Society* for 1766, when he was in his 36th year, a period of life at which Black, Priestley, and Scheele, had already acquired no inconsiderable celebrity. He was not confined to Chemistry only; Electricity, and subjects connected with Meteorology and Astronomy, often occupied his thoughts and employed his pen: his last essay is on the division of astronomical instruments, published in the *Philosophical Transactions* for 1809. He was then in his 78th year, and in full possession of bodily activity and mental energy. After a few days illness, he expired on the 4th of February 1810, in the 79th year of his age.

In private life, he was unambitious, unassuming, bashful, and reserved: he was peevishly impatient of the inconveniences of eminence; he detested flattery, and was

uneasy under merited praise; he, therefore, shunned general society, and was only familiar in a very limited circle of friends. Here he bore his great faculties always meekly: his conversation was lively, varied, and instructive; upon all subjects of science he was at once luminous and profound; and in discussion, wonderfully acute.

We are now about to enter upon that period of our history at which the science was reformed and modified by the French school. Of this chemical revolution I shall endeavour to present a faithful though faint outline. I shall attempt to show the grounds of innovation, to expose the weak parts of the plan, to exhibit its merits, and to compare it with former theories. In the meantime, it may not be improper to take a rapid survey of the ground we have gone over, and to enumerate the materials already in the hands of the reformers.

In the early hypotheses respecting the phenomena of combustion, they were conceived to depend upon the separation of a peculiar principle, called by Stahl and his associates Phlogiston; but the fallacy of these views was shown by Mayow, who, with his predecessor Rey, demonstrated the necessity of atmospherick air in the process. The attention of Chemists was drawn from these subjects early in the eighteenth century, by the new train of investigation in which Dr. Black had successfully embarked, and the field of Pneumatick Chemistry, which was so eminently cultivated by Priestley, Scheele, and Cavendish, absorbed universal attention.

The ideas of the ancients concerning the Elements were now completely subverted. The air we breathe was proved to consist of two distinct aeriform fluids—the one a powerful supporter of combustion and respiration, the other extinguishing flame and exterminating life. Water, so long considered as a primitive body, had been resolved

into simpler forms of matter; in short, novelties of the most attractive kind presented themselves on every side.

The discovery of hydrogen was seized upon by the advocates of phlogiston, as supporting their hypothesis, and it was generally considered as identical with that substance, which had long been hypothetical, but was now exhibited in a tangible form. The reduction of the metallick calces, by hydrogen, was considered as a powerful argument in favour of these notions, and wherever phlogiston had been supposed to be absorbed or evolved, hydrogen seemed to play the part of that imaginary principle.

The views of Priestley and Scheele were combated by a host of petty controversialists, whose names are yet extant, but whose writings are sunk into oblivion—they brought into the field an army of words, but not a single observation, founded upon fact or experiment. Mr. Cavendish was more strenuously and respectably opposed; among those who stood up against his theoretical views, Mr. Kirwan deserves especial mention, for he laid other departments of Chemistry under considerable obligations; but his arguments and learning were of little avail against the tried and sterling facts which he questioned; they are no creditable records to the author, but serve to show the feebleness of subtilty when opposed to the strength of truth.

SECTION VI.

INVESTIGATIONS OF LAVOISIER.

Among the eminent scientifick characters who adorned the last century, Lavoisier has always been looked upon

with high consideration. That his talents were shining, and his career brilliant, cannot be denied; but that he has those high claims to originality which we have been obliged to allow his exalted rivals, has been doubted by the generality of historians, and denied by those who have had access to the most correct information. I shall briefly notice his most important investigations, and afterward endeavour to sketch his character as a Philosopher.

The phenomena of combustion were with Lavoisier, as with his predecessors in the field of theoretical chemistry, a leading object of attention; and the theory of latent heat, devised by Dr. Black, was assumed as the ground-work of his new views.

It has already been stated, that, during the conversion of solids into fluids, and of fluids into vapours, there is a considerable absorption of heat; and that, on the other hand, when vapours and liquids are restored to the fluid and solid form, the heat, which they contained, is evolved, or passes from the latent to the sensible or thermometrick state. These views were assumed by the French school as the basis of their theory of combustion. The gas called by Priestley dephlogisticated air, and by Lavoisier oxygen, was regarded as a compound of a peculiar ponderable basis, united to the matter of light and heat. During the process of combustion, the basis was represented as combining with the combustible, augmenting its weight, and changing its properties; whilst the imponderable elements of the gas, the light and heat, were said to be developed in the form of flame.

Lavoisier instituted an extended and beautiful series of researches connected with this subject. Dr. Ingenhouz had devised the brilliant experiment of burning iron wire in oxygen, but had neglected any inquiry into the change suffered by the gas and the metal. Lavoisier ascertained

that the iron was converted into the black brittle substance, called *martial ethiops* by the old chemists, and that 100 grains of iron absorbed about 100 cubical inches of the gas, and increased 35 grains in weight. Hence martial ethiops appeared to be a compound of oxygen and iron.

Phosphorus was burned in the same manner. There was a considerable absorption of the gas, and it appeared that the phosphorus had sustained a precisely equivalent increase of weight.

The general conclusions deduced from these experiments were bold, but incorrect. It was assumed that oxygen must be present in all cases of combustion; that the base of the gas always unites to the burning body, and that the heat and light essential to the aeriform state of the oxygen are consequently thrown off, or rendered sensible. With regard to the necessity of the presence of oxygen, it may be remarked, that the cases are very numerous, in which bodies burn, and vividly too, independent of that principle, although it is perfectly true that, in the generality of instances, oxygen feeds the flame.

It is, therefore, more philosophical, to consider combustion, or the evolution of heat and light, as a general result of intense chemical action, and as ensuing in all cases where it may be conceived that the corpuscles of bodies are thrown into violent motion, than as depending upon the presence of any distinct substance, or ensuing from the mutual actions of any appropriate forms of matter.

But farther; there are many cases in which oxygen unites to bodies, without the evolution of heat and light, as during the gradual change of some of the metals by exposure to air. And there are numerous instances in which vehement combustion ensues, not only where there is no condensation of air, but where gaseous matter is

positively produced, as in the inflammation of gunpowder; and hence the theory of latent heat, as applied to the composition of gases, is insufficient to account for the phenomena.

Another weak part of the French hypothesis is that relating to the evolution of light, which, if derived from the gas, should be proportional to its consumption or solidification, whereas it depends chiefly on the combustible. Richter, Delametherie, and Gren, regarded the gas as affording the heat only, which is proportional to the quantity consumed; and they supposed the evolution of light to be derived from the combustible, and several modern chemists have espoused this explanation. Phosphorus emits much more light than hydrogen, but consumes less oxygen; hence we should regard phosphorus, as containing more combined light than hydrogen. This hypothesis involves several unnecessary suppositions; but these cannot be discussed without reference to subjects which are excluded by the limits of this discourse. It may, however, here be observed, how nearly the French theory of combustion agrees with that of Rey and Mayow, in referring the increase of weight of the combustible, to the fixation of air: this was the great obstacle in the phlogistick hypothesis, and Rey and Lavoisier overcame it by the same means.

Oxygen was not merely considered by the French school as necessary to combustion, but also as an essential ingredient in all acids (whence the term *oxygen*;) but there are many acids in which no oxygen can be proved to exist, and it is now known even to form a component part of the alcalies and earths. If sulphur be burned in oxygen, it produces sulphurous acid gas: if potassium be heated in sulphurous acid gas, it robs the sulphur of its oxygen, and is converted into potash; here oxygen is seen

alternately producing an acid and an alcali,—the result depending not upon the oxygen, but upon the base with which it combines.

In detailing the discoveries of Dr. Black, I was led to notice his researches concerning the production of fixed air. This gas was also examined with much attention by Priestley, Scheele, and Cavendish, and they have each made important additions to our knowledge of its sources and properties.

Lavoisier's inquiries respecting the composition of fixed air, and its production during the combustion of charcoal and of the diamond, were highly important as connected with his general theoretical views. Black had indeed ascertained that burning charcoal produced fixed air, but rested satisfied with the mere fact, and pursued not the inquiry which is naturally suggested, and which was eagerly taken up by Lavoisier at an early period of his scientifick career. He burned a given weight of charcoal in a given proportion of oxygen gas confined over quicksilver, and when the vessel had cooled, he introduced a solution of potash, which absorbed the fixed air. He thus ascertained the bulk of the fixed air generated by the charcoal, and the bulk of oxygen consumed; and, by weighing the residuum of the charcoal, he found the quantity lost by its combustion. From such experiments, he was led to regard fixed air as composed of oxygen and charcoal, in the proportions by weight of about 70 of the former and 30 of the latter. Soon after the discovery of fixed air by Black, it was demonstrated by Keir, Bergman, and Fontana, to possess acid properties; hence it was occasionally termed aërial acid, cretaceous acid, and mephitick acid. Consistently with the principles of the new nomenclature, it received from Lavoisier the name of carbonick

acid, a term implying that it is composed of charcoal and oxygen; and this it has since retained.

The production of fixed air, or, as we may now call it, carbonick acid, during the combustion of diamond, is one of the most remarkable and important discoveries with which Lavoisier enriched chemical science. The destruction of this precious gem by fire was demonstrated by the Florentine academicians as early as 1690; they exposed a diamond to the focus of a burning lens, and found that it was entirely evaporated; and Francis the First, of Germany, witnessed the same phenomenon in the heat of a furnace. Lavoisier proved that the diamond underwent no change when air was excluded; and that, when ignited in oxygen gas, it produced carbonick acid; whence the inevitable conclusion that the diamond and charcoal are identical in their nature; and that the vast difference in their appearance and mechanical qualities is the result of aggregation; that the one is crystallized, the other in a less indurate form. Unprecedented as such an idea may seem, it is not only warranted by the experiments of Lavoisier and others, but also in some degree supported by analogy. Thus, when argillaceous earth, which is a white pulverulent substance, is aggregated by mechanical attraction into a crystaline form, it constitutes the sapphire, one of the hardest and least destructible of the gems. In one state, the earth is soft, and readily soluble in acids; in the other, its insolubility equals its induration: but there is one invincible anomaly relating to the conducting power of the diamond and charcoal, in regard to electricity; the former ranks among the non-conductors, the latter is a conductor; and hitherto mechanical texture has not been shown, in any analogous cases, to interfere with the power of conducting electricity.

Among those who have further explored the phenomena of the combustion of the diamond, and who have verified and extended the original views of Lavoisier, we find the names of the most eminent European Philosophers. Few subjects in Chemistry have been so eagerly pursued, and the united results of different experimentalists have rarely tallied with the precision which these researches present.[1]

The discoveries of Rutherford and of Priestley, in the years 1772 and 1774, had disclosed the elements of atmospherick air, and several experiments respecting the proportions in which they are blended, had been instituted by these, and other Philosophers. In the year 1775, Lavoisier resumed these inquiries, with a masterly and decisive hand; he heated mercury in contact with a known portion of atmospherick air; it gradually acquired a red film, which after some days ceased to form, and the metal remained unaltered; he then withdrew the fire, and suffered the

[1] That the quantity of carbonick acid, afforded by a given weight of diamond, is the same as that yielded by a similar quantity of charcoal, is the great proof of the identity of those apparently dissimilar substances: this was demonstrated in the year 1796, by the refined and elegant experiments of Mr. Tennant, whose untimely loss society has lately had to deplore. Mr. Tennant was a profound philosopher, and a matchless companion,—his learning was without pedantry; his wit without sarcasm,—he was deep, but always clear; gentle, but never dull. To those who knew him not, it is scarcely possible to offer an adequate representation of his singularly pleasing and enlightened character,—by those who enjoyed his acquaintance, and partook of his social hours, his extent of knowledge, his happy and unrivalled talent for conversation, his harmless but brilliant flashes of merriment, and all his amiable peculiarities, can never be forgotten. Friendship will long continue to weep over his grave, and science to lament beside his tomb.

Mr. Tennant was born in Yorkshire in 1761, and died at Boulogne in 1815.

See *Biographical Account* of Smithson Tennant, Esq. in Thomson's *Annals of Philosophy*, Vol. VI.

vessels to cool; he found that the air had diminished in bulk, and that the quicksilver had increased in weight; that the loss of the former was equivalent to the gain of the latter —which had absorbed the oxygen of the air, leaving the azote unaltered. By such investigations he arrived, with tolerable precision, at the proportion in which these gases exist in common air, and found, that, by mixing forty-two parts, by measure, of azote, with eight parts, by measure, of oxygen, he produced a compound precisely resembling our atmosphere, in its power of supporting combustion and respiration, and of contributing to the calcination of the metals.

Besides these researches and discoveries, Lavoisier was the author of many scientifick papers in the *Memoirs of the Parisian Academy.* Of these a brief and hasty notice will suffice, as they relate not to the great reform of chemical theory, in which he was so conspicuous an actor, and upon which his fame and reputation have chiefly been raised.

In 1764, the French Government proposed, as a prize question, "Which is the best method of illuminating the streets of a large metropolis?" It was answered by Lavoisier; and he was rewarded with an honorary medal. In 1768, he became a member of the Academy. In 1770, he controverted a prevailing opinion respecting the convertibility of water into earth; and, two years afterwards, published an ingenious geological essay upon the changes and stratification of the globe. In 1774, he entered upon the grand field of discovery which has occupied so much of our attention, and published an ingenious and comprehensive view of Pneumatick Chemistry. A few years afterwards, his theory of acidity, of combustion, and of oxidizement; his experiments upon the composition of water, and of the atmosphere, and his views respecting the

nature and affections of heat, were successively presented to the publick; and, in 1789, his work entitled *Elemens de Chimie* was given to the world. It contains a full account of his theoretical views and experimental researches.

Lavoisier was an earnest promoter of the Chemistry of the Arts. He turned his attention to the improvement of several manufactures, and his labours were rewarded by considerable success. Agriculture was with him a favourite pursuit, and he endeavoured to improve its processes by experimental research. He was an able Political Economist; and, for a few years, filled the office of a Commissioner of the National Treasury, with honour to himself, and benefit to his country.

The moral and social character of Lavoisier was of the most estimable cast. Contemporary historians agree in eulogizing his mild, amiable, and obliging manners; in extolling his liberality, and in praising him, as the encourager of deserving ingenuity, and the ardent patron of science and the arts.

Through the scenes of the Revolution, such a man could not expect to pass unmolested. He was rich, and therefore criminal; virtuous, and consequently offensive. In short, because his publick character and private life were equally unimpeachable and blameless, he was marked out for destruction, and murdered upon the scaffold on the 8th of May 1794, in his native city of Paris, and in the 51st year of his age.

Upon these acts of iniquitous barbarity and inhuman treachery, equally degrading to the individual performers and to the beholding nation, it is neither my business nor inclination to dwell; the recital of particulars would excite disgust rather than interest; and would rather shock than inform.

We must now divest ourselves of the impressions naturally arising out of the virtues, the eminence, and the mis-

fortunes of Lavoisier, and with unmixed attention steadily reflect upon his philosophical character. By some he has been extolled as the most original, inventive, and exalted genius of his age; by others stigmatized as an universal and dishonourable plagiarist; but these are the extremes of panegyrick and malevolence, each equidistant from candour and from truth. He was doubtless an acute, sagacious, and useful Philosopher; his zeal for the welfare of science was unremitting and exemplary, and his affluence enabled him to pursue it upon an extensive and splendid scale. As an original discoverer, he bends before Black and Priestley, and was inferiour to Cavendish and Scheele; but, as a theorist, he has few equals; he was comprehensive, successful, and clear. If time has shaken his opinions, and loosened his speculations, the change must be referred to the imperfect and progressive state of Chemistry, rather than to their inherent futility. In Natural Philosophy, the systems of Pythagoras, Ptolemy, Descartes, and others, have successfully yielded to the satisfactory and apparently stable simplicity of the Newtonian doctrines; but the Newton of Chemistry is yet to come.

It must be regretted, that those who have censured Lavoisier with the uncandid and unacknowledged appropriation of the thoughts of others, have some grounds for the accusation. In bringing forward his theory of combustion, why did he smother the lucid opinions of Rey and Mayow? why refuse praise and acknowledgments to Black, and Scheele, and Cavendish? or, why appropriate the discovery of oxygen, in the face of the prior, indisputable and known claims of his friend and contemporary Priestley? These are questions we cannot now answer; but, those who have grounded harsh, indiscriminate, and severe censure, upon such accusations, have neither been animated by the independent spirit of true philosophy,

nor guided by the unbiassed love of truth. It must be remembered, that Lavoisier was never fairly confronted by these rivals and antagonists; that unintentional inadvertency often accompanies scientifick ardour, that, in the eagerness of pursuit, he may have neglected that which, in a calmer hour, he would have seen, regretted, and acknowledged; and that, in the hurry of discussion and heat of controversy, he was suddenly summoned to eternity.[1]

Though these considerations do not exculpate our philosopher, they must be allowed to extenuate his imputed

[1] Since writing the above, I have seen two scarce volumes of the posthumous works of Lavoisier in Mr. Hatchett's library at Roehampton. They consist, in great measure, of extracts from, and sketches of his different papers read before the Royal Academy of Sciences, but several original Observations and Essays are also dispersed among them. They, in some degree, justify the observation which I have made in the text, that, had Lavoisier lived, he would have done merited justice to his predecessors and contemporaries, for he candidly reviews their opinions, and compares them with his own; at the same time, the following passage cannot be regarded as perfectly candid towards Rey, who, as I have shown above, founded his arguments not upon hypothesis, but upon experiment.

I insert a long quotation, that there may be no misunderstanding upon the subject.

After stating the prevailing phlogistick notions entertained at that period, he proceeds as follows: "Tel étoit l'etat des connoissances, lorsqu'une suite d'expériences, entreprises en 1772 sur les différentes espèces d'air, ou de gaz qui se dégagent dans les effervescences et dans un grand nombre d'opérations chimiques, me firent connoître, d'une manière démonstrative, quelle étoit la cause de l'augmentation de poids, qu'acquiérent les metaux lorsqu'on les expose à l'action du feu.— J'ignorois alors ce que Jean Rey avoit écrit à ce sujet en 1630; et quand je l'aurois connu, je n'aurois pu regarder son opinion à cet égard, que comme une assertion vague, propre à faire honneur au génie de l'auteur, mais qui ne dispensait pas les chimistes de constater la verité de son opinion par des expériences. J'étois jeune, j'étois nouvellement entré dans la carrière des sciences, j'étois avide de gloire, et je crus devoir prendre quelques précautions pour m'assurer la propriété de ma découverte. Il y avoit à cette époque, une correspondance habituelle entre les savans de France et ceux d'Angleterre; il regnoit entre les deux nations,

failings—they should induce us rather to soften the asperities of his scientifick character, than to magnify its faults—instead of rejoicing that he was not perfect, we should

une sorte de rivalité qui donnoit de l'importance aux expériences nouvelles, et qui portoit quelquefois les écrivains de l'une ou de l'autre nation, à les contester à leur véritable auteur; je crus donc devoir déposer, le 1er Novembre 1772, l'écrit suivant cacheté, entre les mains du Secrétaire de l'Académie. Ce dépôt a été ouvert à la séance du 5me Mai suivant, et mention du tout a été faite en tête de l'écrit. Il étoit concu en ces termes :—

"Il y'a environ huit jours que j'ai découvert, que le soufre en brûlant, loin de perdre de son poids, en acquiéroit au contraire; c'est à dire, que d'une livre de soufre, on pouvoit retirer beaucoup plus d'une livre d'acide vitriolique, abstraction faite de l'humidité de l'air; il en est du même du phosphore : cette augmentation de poids vient d'une quantité prodigieuse d'air qui se fixe pendant la combustion, et qui se combine avec les vapeurs.

"Cette découverte que j'ai constatée par des expériences que je regarde comme décisives, m'a fait penser que ce qui s'observoit dans la combustion du soufre et du phosphore, pouvoit bien avoir lieu à l'égard de tous les corps qui acquiérent du poids par la combustion et la calcination: et je me suis persuadé, que l'augmentation be poids des *chaux* métalliques, tenoit à la même cause. L'experience a complettement confirmé mes conjectures : j'ai fait la reduction de la lithrege dans des vaisseaux fermés, avec l'appareil de Hales, et j'ai observé qu'il se dégagéoit, au moment du passage de la *chaux* en métal, une quantité considérable d'air, et que cet air formoit un volume au moins mille fois plus grand que la quantité de litharge employée. Cette découverte me paroissant une des plus intéressantes qui ait été faite depuis Stahl, j'ai cru devoir m'en assurer la propriété, en faisant le present dépôt entre le mains du Secrétaire de l'Académie, pour demeurer secret jusqu'au moment où je publierai mes experiences."

(Signé) "LAVOISIER."

"En rapprochant cette première notice de celle que j'avois déposée à l'Académie le 20me Octobre précédent, sur la combustion du phosphore, du mémoire que j'ai lu à l'Académie à sa séance publique de Pâques 1773, enfin, de ceux que j'ai successivement publiés, il est aisé de voir, que j'avois concu dés 1772, tout l'ensemble du systême que j'ai publié depuis sur la combustion. Cette théorie à laquelle j'ai donné de nombreux développemens en 1777, et que j'ai porté, presque dés cette époque à l'état où elle est aujourdhui, n'a commencé à être ensignée par Fourcroy, que dans l'hyver de 1786 à 1787; elle n'a été adoptée par Guyton Morveau, qu'à une époque postérieure; enfin, en 1785 Berthollet écrivoit encore dans le systême du phlogistique. *Cette theorie*

delight in his excellence, and should estimate his character as a Philosopher, not so much by the means he employed, as by the noble effects produced.

Among many other subjects which engaged the attention of Lavoisier and his associates, that of reforming the nomenclature of Chemistry deserves to be noticed as highly beneficial to the promotion of the science, and as tending materially to facilitate its acquisition. I am inclined, however, to think that, upon this point, too much credit has been given to the French school; rage for innovation, and not zeal for improvement, seems often to have guided the undertaking; and terms, once deemed faultless, now appear not less absurd and objectionable than the fanciful names employed by the alchemical writers.

As principals in the formation of the new nomenclature, we find the names of Guyton Morveau[1] and Fourcroy, two men who may certainly be considered as ornaments of their age and country. The former, amidst varied avocations, prosecuted Chemistry with successful diligence, and, had he given nothing else to the science, his name deserves to be transmitted to posterity, as the inventor of the means of destroying infection by acid vapours, the efficacy of which he first pointed out in the year 1773. His first essay on the reform of nomenclature was published in the *Journal de Physique* for May, 1782, and although it was strenuously opposed by the colossal power of the Royal Academy of Paris, the plan was not only afterwards approved, but prosecuted by the eminent Chemists of that metropolis. The different papers and correspondence re-

n'est donc pas, comme je l'entends dire, la théorie des Chimistes Francois: elle est la mienne, et c'est une propriété que je réclame auprés de mes contemporains et de la postérité."

[1] Born at Dijon in 1737. Died at paris in 1815. See *Life* by Dr. Granville in the *Journal of Science and Arts*, Vol. III. p. 249.

lating to this subject are in many respects, curious and interesting from the difference of opinion which prevailed respecting the terms he adopted, and the ultimate benefit likely to result from the reformation.

Fourcroy[1] is a well known name in the chemical world; his works rank among the most celebrated which France has produced in the science of Chemistry, though they are sometimes deficient in candour, and sometimes in correctness. His labours were important, and his discoveries numerous, but they are in many respects, so closely interwoven with those of contemporary Philosophers, that I have deemed it expedient to wave farther notice respecting their objects and merits.

I have now brought my narrative to the conclusion of the last century, about which period Electricity began to assume importance as a chemical agent, and the *Voltaick* apparatus became a necessary implement of the laboratory. To this source, the new aspect which chemical science now wears, may principally be referred, and the historian, who shall in aftertimes record the advances that have been made in Chemistry during the last eighteen years, will excite triumphs of the human mind never excelled, and rarely equalled.—I am apprehensive that the inquisitive eye will detect several omissions in the foregoing pages, although I have diligently endeavoured to record every important event in the general history of the science. Of many who have attained deserved eminence in the exclusive pursuit of its distinct branches, no mention has been made: I have looked with attention into their works, and am well aware of their individual merits; but I should have swerved from the principal object of this Dissertation, that of recording discoveries, had I attempted even the superficial enumeration of their infinitely varied applications.

[1] Born in Paris in 1755, where he died in 1809.

Date Due